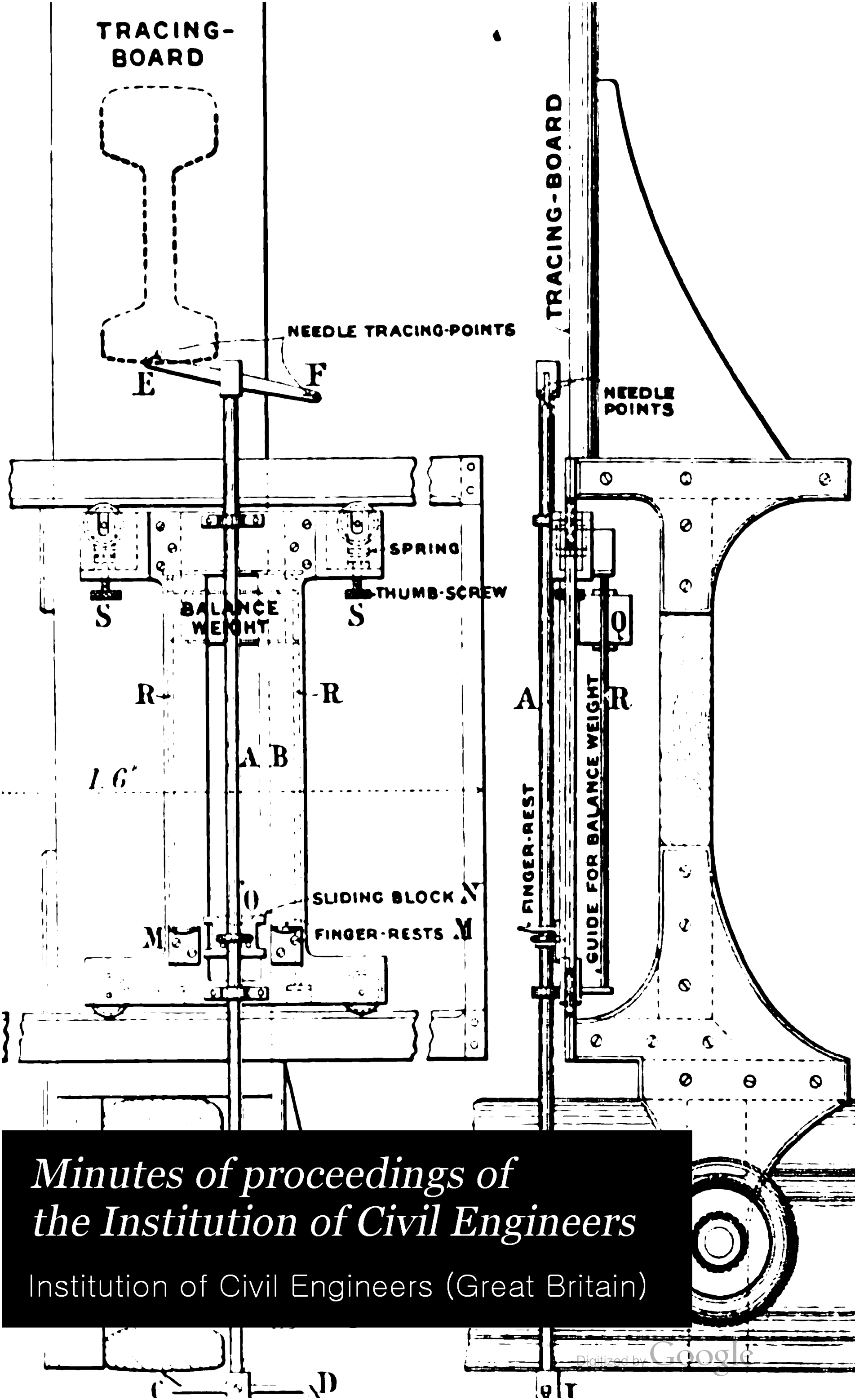
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INDEXED.

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CLXX. 1906-7

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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CORRIGENDA.

Vol. cl, p. 271, *for* "B.Th.U. $= W(H_1 - h_s) + 0{\cdot}48\,(t_s - t_1)$"
read "B.Th.U. $= W\{H_1 - h_s + 0{\cdot}48\,(t_s - t_1)\}$"

„ „ p. 272, *for* "B.Th.U. $= W\,(1{,}114 + 0{\cdot}305\,(t_1 - t_s)) + 0{\cdot}48\,(t_s - t_1)$
read "B.Th.U. $= W\,\{1{,}114 + 0{\cdot}305\,(t_1 - t_s) + 0{\cdot}48\,(t_s - t_1)\}$

„ clxvii, p. 241, line 13, *for* "larva" *read* "larvæ."

„ „ p. 247, „ 8, *for* "strata" *read* "stratum."

„ „ p. 419, „ 13, *for* "joint" *read* "point."

„ „ p. 470, „ 33, *for* "lead" *read* "head."

„ clxix, p. 246, „ 7 from bottom, *for* "to 11,000" *read* "20,000."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1906-1907.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS

19 March, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

(*Paper No. 3675*).

"The Victoria Falls Bridge."

By GEORGE ANDREW HOBSON, M. Inst. C.E.

THE Victoria Falls of the River Zambezi are situated on the boundary which divides the administrative Provinces of North-Western and Southern Rhodesia in the territory governed by the Chartered Company of British South Africa. They lie about 6° within the Tropic of Capricorn, and about midway between the shores of the South Atlantic and Indian Oceans.

The Falls were unknown to civilization until their discovery in the year 1855 by David Livingstone; and owing to their remote position, and the great difficulty and expense of reaching it, one of the grandest spectacles of Nature remained almost unvisited by white people until well within the last decade.

The Victoria Falls, named by their discoverer after the late Queen, now possess a railway-station for passengers and goods, which is situated on the main route of the railway projected by the founder of Rhodesia to connect Cape Town with Cairo; and a bridge close by the cataract carries the railway across the grand chasm formed by the River Zambezi.

The rails reached the bank of the river in May, 1904, the distance from Cape Town on the south being 1,641 miles, and from Beira on the east coast 950 miles. Twenty years before, it took over 6 months' trekking with oxen to get there from the sea. Now the distance is easily covered in a few days.

The survey of the ground for the bridge was made during the time the Boer War was raging; communications southwards were cut, and the construction of the railway was much delayed, but

never quite suspended, through military operations. In 1901, after the siege was raised, and Mr. Rhodes was released from Kimberley, he was shown at his office in London a sketch of the bridge it was then proposed to build. Although he had never visited the locality, he was sufficiently familiar with it from travellers' descriptions and engineers' surveys to indicate in a general way the point of crossing. He determined that passengers in the trains going over the bridge should have a view of the falls; and as the site upon which the bridge now stands is practically the only one which could fulfil this purpose, it may be said to have been chosen by him. The preliminary design of the bridge above referred to was prepared to meet Mr. Rhodes's views, and it received his approval.

The choice of the site was finally governed by the natural formation of the walls of the chasm, advantage being taken of the minimum distance to be spanned, combined with the soundest foothold obtainable. The position fixed upon is about 700 yards below the cataract (Fig. 1, Plate 1).

The profile of the chasm at this spot is very striking (Figs. 2, Plate 1). The width at the top is approximately 650 feet, whilst the depth from the general level of the ground to the surface of the water below is about 400 feet. The left or north bank of the river is an almost perpendicular cliff, but the opposite bank has a shelf about half way up, and the whole region is composed of erupted rock, mostly basalt.[1] The general level of the surrounding country is 3,000 feet above sea-level.

The rock being very hard, the bridge was designed to fit the profile of the gorge with as little expenditure on excavation as possible; and it would have done so, but for a mistake made by the surveyor in concluding that the rock on both sides was solid. The mistake was perhaps excusable, and was not discovered until the vegetation which thrives in the hot sun and the spray from the falls had been removed, and the work of clearing the ground and the excavation of the rock had proceeded for some time. It was then found that the shelf on the right bank on which it was intended to rest one end of the principal span was covered to a considerable depth with debris. By the time the error had been discovered, the preparation of the steelwork was too far advanced to permit of any alteration being made in the structure. The difficulty had therefore to be overcome partly by increasing the depth of the concrete

[1] See G. W. Lamplugh, "Report on an Investigation of the Batoka Gorge and Adjacent Portions of the Zambesi River." Report of the British Association, 1905, p. 292.

foundations, and partly by lowering the level of the entire bridge to the extent of 21 feet; but both time and money would have been saved had the true facts of the case been recognized at the beginning, the span designed 25 feet longer, and the truss increased in depth at the ends by 20 feet.

General Design.

So far as the type of bridge was concerned, there was no difficulty in making a choice. Several kinds were considered, but the nature of the situation and the purpose of the work made it obvious that a two-hinged spandrel-braced arch was the only one worth considering, as it completely and satisfactorily answered all the requirements of the case. These may be summarized as:—(1) Handsome appearance; (2) Rigidity; (3) Economy; (4) Ease of erection, cantilever-wise, without scaffolding. A steel arch of this character was therefore designed to spring from the rock walls of the Zambezi chasm, to be erected cantilever-wise simultaneously from both sides (Figs. 2, Plate 1). The best, though not the earliest, example of this type is the bridge which in 1897 replaced the suspension-bridge, and now carries the Grand Trunk Railway over the Niagara Gorge.

Perhaps the alternative of a three-hinged arch would have been preferred by some, but it was rejected here for want of rigidity under railway-traffic. This type is known to have been much favoured on the Continent, but there are instances where great uneasiness has been felt by the designers, in consequence of excessive longitudinal vibration having developed in the structure under traffic at even moderate speeds. The calculation of the stresses in the two-hinged arch is the more laborious, and a certain amount of expense is incurred in making sure that the bridge takes its correct stress; but the expense is small compared with the difference in cost of the two types, the two-hinged type being the more economical as well as the more rigid. Mr. J. A. L. Waddell, M. Inst. C.E., calculates the difference in weight of the two types to be 2 per cent.[1]

In the braced-rib type the load is borne wholly by the arc, that being the object of the design; the top chord and the supports which carry it are only a platform resting on the arc; they do not relieve it of any stress, nor do they tend to stiffen it, whilst a considerable plant is necessary for its erection. In the braced-spandrel type the reverse is the case. The top chord performs a double function, for

[1] See pp. 41 and 49.—Sec. Inst. C.E.

whilst affording a platform it relieves the arc of some of the stress. The temperature-stresses are higher, but this type lends itself better to erection than any other; every part assists in the erection of the whole, and little additional material is required.

Each main girder of the Victoria Falls bridge is therefore a spandrel-braced arch standing on two hinge-pins, and is similar in principle to the Niagara Falls girders referred to above; it differs from the latter, however, in the span, the depth, the load, the roadway, and all the details of construction. The means adopted in erection also differed radically from those employed at Niagara, being simpler and cheaper.

The conditions of loading and details of construction were the following:—

The bridge is designed to carry two lines of way of the usual South African gauge, 3 feet 6 inches. The existing line from Cape Town to the bridge (with unimportant exceptions) is a single track, but a width sufficient for a double line across the bridge was considered to be necessary in order to provide lateral stability.

In addition to the dead load, the forces which the bridge is calculated to sustain are:—

(1) A train on each line of way consisting of two engines, measuring 100 feet long and weighing 1·75 ton per lineal foot, followed by heavy trucks weighing 1·33 ton per lineal foot.

(2) Temperature-stresses caused by a variation of 60° F. above or below the mean.

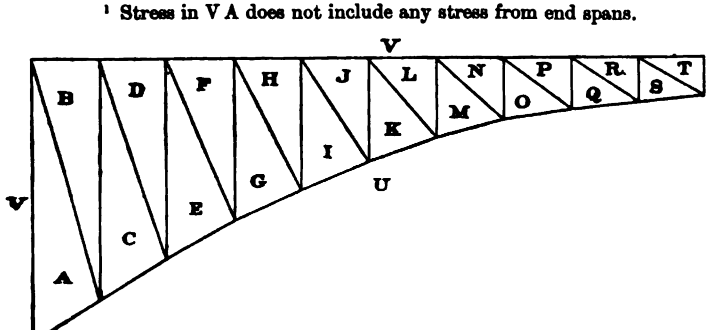
(3) Wind-stresses due to a wind-pressure of 30 lbs. per square foot on the train and bridge, or 45 lbs. per square foot on the bridge alone. The pressure is calculated on the entire area of both arches, and stresses due to unequal distribution of such pressure are allowed for.

The stresses were calculated by Clerk Maxwell's method, described generally in the "Encyclopædia Britannica" by the late Professor Fleeming Jenkin, and in detail by Professor Charles E. Greene, of Michigan University, in his work, "Trusses and Arches analysed and discussed by Graphical Methods," Part III. With the data which the formulas there given provide, it is a simple though a long and laborious process to ascertain the stresses in the various members which compose the arch. This task was performed by Mr. Ralph Freeman, Assoc. M. Inst. C.E., assistant to the engineers.

For each member of the bridge the position and length of train producing maximum and minimum stresses were found, and the actual stress in the member corresponding with this particular train-load was calculated. These stresses were then converted to equivalent

Member.		Stress in Tons due to				
		Train.		Structure.	Temperature.	Wind.
		Maximum.	Minimum.			
Chord	BV	+ 36	− 25	+ 12	± 4	∓ 19
	DV	+ 75	− 51	+ 24	± 9	∓ 58
	FV	+116	− 79	+ 37	± 16	∓ 88
	HV	+158	−107	+ 51	± 25	∓110
	JV	+203	−133	+ 67	± 38	∓120
	LV	+255	−153	+ 87	± 54	∓125
	NV	+293	−157	+111	± 74	∓120
	PV	+307	−133	+139	± 98	∓110
	RV	+287	− 76	+163	±118	∓ 97
	TV	+224	− 20	+173	±126	∓108
Rib	AU	+538	− 0	+467	∓ 25	±215
	CU	+517	− 4	+437	∓ 29	±172
	EU	+508	− 14	+410	∓ 35	±132
	GU	+500	− 29	+385	∓ 41	± 88
	IU	+493	− 50	+360	∓ 50	± 51
	KU	+486	− 69	+335	∓ 62	± 12
	MU	+475	− 85	+308	∓ 77	∓ 14
	OU	+444	− 91	+278	∓ 97	∓ 48
	QU	+384	− 74	+248	∓119	∓ 80
	SU	+285	− 52	+222	∓139	∓107
Posts	VA[1]	+164	− 83	+104	±14	±128
	BC	+158	− 76	+ 78	±15	±11
	DE	+151	− 65	+ 68	±16	±12
	FG	+139	− 53	+ 62	±17	±14
	HI	+129	− 42	+ 56	±18	±18
	JK	+119	− 28	+ 53	±19	±18
	LM	+110	− 19	+ 51	±19	±20
	NO	+109	− 35	+ 49	±17	±19
	PQ	+118	− 55	+ 43	±13	±14
	RS	+122	− 89	+ 34	± 5	± 7
Diagonals	AB	−130	+ 86	− 45	∓15	± 1
	CD	−123	+ 80	− 37	∓16	∓ 3
	EF	−118	+ 70	− 32	∓18	∓ 7
	GH	−111	+ 62	− 30	∓20	∓11
	IJ	−107	+ 51	− 29	∓22	∓17
	KL	−105	+ 36	− 31	∓25	∓21
	MN	−109	+ 36	− 34	∓28	∓26
	OP	−129	+ 58	− 35	∓29	∓27
	QR	−169	+125	− 28	∓24	∓25
	ST	−193	+177	− 11	∓10	∓14

[1] Stress in V A does not include any stress from end spans.



fixed stresses by the addition of an increment for impact equal to $\frac{300}{500 + L}$ of the range of stress due to the train, L being the length (in feet) of the train producing the stress.

In order to determine the wind-stress it was assumed that one-half of the total pressure concentrated at the chord-joints passes along the upper wind-trusses and down the end post to the abutment, the other half being transferred vertically to the lower truss, and thence to the abutment. One-half the maximum wind-stresses were allowed for in addition to the maximum stress due to the structure, train, and temperature, the last being treated as a fixed stress.

The actual stresses in the members of the trusses from which the cross-sections of the members are proportioned are shown on p. 5.

The steel of which the structure is built is subjected when under the maximum stress, including all increment for impact, to a load of 8 tons in tension, and 7 tons in compression, per square inch.

The bridge consists of three spans. The end span on the left bank of the river is 62 feet 6 inches, and that on the other bank 87 feet 6 inches. These spans are composed of braced girders of ordinary type, 12 feet 6 inches deep, with horizontal upper and lower chords, and divided into square panels. The girders are fixed 20 feet apart. Connected with the end posts of the central span, they unite it with each bank of the river in a direct and simple manner. The deck is horizontal, and is laid on the top chords throughout the bridge.

The central span is 500 feet from centre to centre of bearings, with a rise of 90 feet. The curvature of the arched rib is parabolic. The panels, twenty in number, are 25 feet in length. The depth of the girder at the crown is 15 feet, and at the abutment 105 feet. Each main girder stands in a plane at an inclination of 1 in 8 from the perpendicular. The width between the centres of the girders is 27 feet 6 inches at the top, and 53 feet 9 inches at the springing level, and the width between the parapets 30 feet. There is a camber of 9 inches in the top chord.

Skew-backs and Bearings (Figs. 3–5, Plate 1).

The entire bridge, with the exception of the main bearings, weighs approximately 1,500 tons. When the live load (1,820 tons) is added to this a vertical load of 3,320 tons has to be supported by the foundations, of which only about 280 tons is borne by the outer ends of the shore spans, the greater portion being carried by the four bearings of the principal span. The total pressure due to the horizontal thrust of the arch and stresses due to temperature and

wind-pressure is more than double this load. The calculated thrust which passes through each of the four hinged bearings amounts to 1,600 tons. On this account alone these bearings constitute a very important feature in the work; and when it is considered that their duty is also to afford the steel frame of the bridge freedom to respond to wide variations of temperature without distorting itself or causing excessive strain, their importance can hardly be exaggerated.

In designing the bearings the first part of the problem was to provide a means whereby the stresses which pass through the main rib, a hollow structure, whose sectional dimensions are about 3 feet square, could be collected and concentrated upon a straight line at right angles, not to the rib itself but to the resultant thrust of the arch, the straight line being the centre-line of the hinge bearing-pin on which each quarter of the bridge rests. In the next place the whole of the stresses have to be redistributed from this centre-line to the rock through a series of parts composed of bearing, pedestal, base-plate, and concrete monolith.

The thrust through each bearing being the considerable one of 1,600 tons, something of a substantial nature and thoroughly reliable in every way had to be devised. It will be conceived that this purpose could be readily effected by means of a casting, which, indeed, is the method usually adopted. It was felt, however, that the present case was not one in which to run any risk of failure through defective castings; nor was there any necessity to do so. Notwithstanding the great strides which have taken place in steel-foundry practice, there are still risks, if not of honeycombing, then of unequal contraction, and the setting-up of unknown internal stresses in the casting of steel from entirely new patterns. Moreover, the units of construction in this case had to be of a weight convenient not only for transportation to the site, but more especially in respect of handling and lowering into positions very difficult of access. A heavy casting was on this account undesirable.

An essential feature of the design is the uniform distribution of the load over the various parts which compose the bearing. The load must be placed uniformly upon the length of the pin, and in like manner the pin must be supported in its bearing, so as to avoid bending. The load having thus been transmitted to the pin, it must be equally distributed through the pedestal and thence to the base-plate which rests upon the concrete, so that the load on the latter may be uniform per square foot of bearing-surface. In order that the arch may fall and rise and the top chord may expand and contract with perfect freedom through a wide range of temperature, the hinges must be set square to the longitudinal axis of the bridge, not

square to the arch-rib itself. The pin and its fellow in the opposite bearing must lie in the same straight line, like the hinges of a box-lid; if set otherwise they would bind. Figs. 5, Plate 1, show how these principles have been carried into effect.

The hinge-pin is 12 inches in diameter by 5 feet 10 inches in length; it is made from a solid steel forging accurately turned all over, and a bolt-hole is drilled through the axis. Regarded in front elevation, the whole bearings, the pins especially, appear to be of very small dimensions, compared with the superstructure they carry. But they are of solid construction, and made of the strongest and toughest materials practicable. The pin itself is subjected to no greater pressure than 2½ tons per square inch.

The arch-rib terminates with a simply-constructed square end, and is borne by a steel beam of colossal section, having a web 4½ inches thick, placed cross-wise to the rib of the arch. The beam is a solid steel forging and performs the double duty of collecting and redistributing the load transmitted from the rib to the pin, and of giving the correct angular set to the springing of the arch. For the latter purpose the flanges of the beam are not made parallel to each other. The lower flange which stands on a saddle—also of forged steel—over the pin, is horizontal, while the upper flange is inclined to give the true direction to the arch-rib. The flanges of the beam are accurately planed to make true bearing-surfaces. All the work is plain and square, except in this beam, and here all the difficulties are assembled and are dealt with at once.

The base of the end-post is treated in a similar manner. The upper flange of the beam here is inclined at 1 in 8.

The two forged beams, which are connected together at the top by means of a heavy bent plate and diaphragms, form pillars through which the entire thrust of the arch and the end post respectively must pass to the pin. No element of doubt could therefore be allowed to enter, either as to the form or the system of manufacture of these pillars. Steel forgings were accordingly adopted as affording the lightest and most reliable means of meeting all the requirements.

The bearing-pin is carried in a forged steel cup, turned, bored, and fitted on a triangular shaped pedestal, which is built in six sections of thick steel plates. These plates are united on the centre-line by means of channels placed back to back, and bent at the top to form a semi-circle of the same radius as the cup which holds the pin, while at the bottom they are bent square to form a base. Each section of the pedestal supports one-sixth of the total load, and they are all riveted to a plate 1 inch thick and 5 feet 6 inches square. The base of the pedestal being of too small an area to distribute the load

in the concrete foundation, the load attaining 53 tons per square foot, a base-plate 11 feet 6 inches by 6 feet 6 inches was provided, the effect of which was to reduce the load on the concrete to 21 tons per square foot.

The base-plate proper is composed of seven rolled steel beams, 18 inches by 7 inches by 75 lbs. per lineal foot, well riveted top and bottom to thick plates, the centres of the beams corresponding with the compartments in the pedestal above. The greatest possible care was taken to make the pedestal and base-plate true and out of winding, as it was recognized that one setting here would give the direction and correct distance for the bearing-pin, and therefore of the whole structure.

After the parts composing the pedestal and the base-plate respectively were riveted together, all the bearing-surfaces were planed.

For convenience in setting the bearings and erecting the superstructure, the lower part of the top of the concrete foundation was designed level to form an angle with the inclined part (Figs. 5). The corner of the angle thus formed is in exact parallelism with the centre of the pin; thus in setting out the work, before the bearings were placed on the concrete base, it was easy to ascertain the correct position of the pin. The corner of the angle in the concrete also provided an excellent base-line, square to the axis of the bridge, and the distance from the one to the other on the opposite bank was equal to the exact span of the steel structure, 500 feet, measured from centre to centre of the bearings.

When the base-plate was put in place, it was carefully adjusted by means of wedges, and when absolute accuracy of position and elevation had been attained, cement grout was forced, under pressure, through a series of pipes specially located for the purpose, over the whole bearing area (Figs. 5).

Scarcely inferior to the bearings in importance is the question of the joining of the two arms of the bridge at the centre. Each half of the arch was designed to meet the other with a butt-joint in the arch-rib (Figs. 9, Plate 2), and when in the course of erection the two half-arches met at this joint, their temporary character of cantilevers ceased, and the structure was transformed for the moment into a three-hinged arch, the top chord having a clearance or gap of several inches left in it. In this condition it is evident that the top chord and the spandrel-bracing only perform the duty of stiffening the arch, whilst they are themselves supported by it, and there is obviously no stress whatever in the central member of the top chord. In order, therefore, to secure the proper distribution of stress in all members due to the complete structure, it was necessary to impart the correct stress to this member artificially.

With this object, hydraulic jacks were inserted in recesses prepared in the top chord adjacent to the gap, and the ends of the top chord were forced asunder until the required stress was imparted, regard being had to the temperature at the moment. Packings were afterwards specially made to fill the gap exactly. Joint-covers were then added, the rivet-holes at one end of each chord being drilled on the spot (Figs. 9). A Table was prepared of the hydraulic pressures to be exerted in order to obtain the correct compression in the chord.

Details of Steelwork (Plate 2).

The cross girders, spaced 12 feet 6 inches apart, rest on the top chord, and their seats are bevelled to correspond with the angle of inclination of the main girders (Figs. 6), which makes a simple and satisfactory arrangement alike for construction and for erection. They are of a simple plate type, 30 feet long and 2 feet 6 inches deep over angles. The rail-bearers are fixed on top of the cross girders, and are of the continuous trough type, which was the Rhodesia Railway standard at the date of this design, and the adoption of which, in a great measure, governed the spacing of the cross girders.

With the exception of the top chord members, which are strengthened to resist the bending due to the intermediate cross girders, the cross sections of the members are symmetrical about both axes. All members have solid plates and angles on their two vertical faces, with transverse lattice bracing on the top and bottom or on the sides. The bracing performs only the function of uniting the sides, and the bars are so disposed that they can be used as rungs of a ladder for access to all parts. Care was exercised in designing the details to ensure simplicity in all sections, and the avoidance of enclosed parts or hidden spaces anywhere in the structure was kept steadily in view. There are no cavities for holding water, nor any surfaces where moisture can condense, the air being free to circulate everywhere. All the parts, in fact, are designed to be visible to the eye, and easily accessible to the painter's brush.

The form of member described is easily constructed as well as easily inspected and painted. The joints are simple, effective and economical.

The cover-plates were designed so that the rivets would take all the stress passing through the member, the number and aggregate section of the rivets being suitable for this purpose. At the same time the joints are planed to true surfaces, so that the plates and angles abut accurately against each other. The butt-joints of the main arch-rib were planed to the exact angle calculated for each joint. This angle differs in every

instance in the half span, owing to the curve being parabolic and not segmental. Every effort was made to attain accuracy and soundness of construction, and to this end the lengths of the members between the joints of the 25-foot panels were specified to vary not more than $\frac{1}{32}$ in. from the calculated length. With few exceptions, all rivets were accessible for mechanical closing, the absence of box-sections making this easy to accomplish.

To facilitate erection and secure accuracy in alignment, a turned steel pin was inserted at the point of intersection of each vertical and diagonal member with the top chord and arched rib. To make the handling of it easy at a critical moment in an awkward position the pin was designed to be of the least possible weight. Not being intended to carry an accumulated stress, but only that due to the weight of a single panel with the addition of a portion of the erecting-plant, the weight of the pin did not exceed 30 lbs. (Figs. 10). The point was temporarily fitted with a cone to facilitate its being threaded through the holes in the plates. This system proved advantageous in every respect. Time in erection was saved and, once the pin was in its place, confidence in the accuracy of the work so far done was at once established. Reinforcement of the pin by rivets or service bolts was a matter that could be attended to when all the members constituting one panel were in place, and it was not necessary to wait for the insertion of all the rivets in one particular panel before proceeding with the work of erecting the next.

In order to check the accuracy and completeness of the work done in the bridge-yard, the erection on the contractor's premises of the whole of the work in sections was determined upon, and it may be here stated that this was so effectively performed that troubles which would otherwise have been caused at the site, through mistakes of commission or omission, were entirely obviated. When the steelwork was erected at the Victoria Falls, all the members met accurately together in their respective positions.

Horizontal struts are provided to shorten the unsupported lengths of the vertical struts, but they are not rigidly attached to the diagonal ties.

In addition to vertical transverse bracing between the posts, the wind-bracing consists of two distinct horizontal systems. The upper system immediately under the cross girders is divided into almost square panels, 25 feet between centres, corresponding with the vertical members of the arch. The cross girders form an additional strut, but are not recognized as such, the system being complete without them. The lower system is attached to the arched rib and is divided into twenty-five bays, which vary in width

from 53 feet 9 inches at the springing to 30 feet at the centre of the span. In order to reduce the columnar length of the members, subsidiary struts are introduced, the general construction being the same in both systems.

Some difficulty was met with in designing the connections of the wind-bracing with the booms of the arch owing to the latter's inclination. The booms lie at an angle of 1 in 8 from the perpendicular, while the bracing is square to a vertical plane. The connecting plates had therefore to be bent to the required angle.

The vertical bracing is in one or more panels according to the length of the posts (Figs. 8, Plate 2).

The end posts (Figs. 6) have a total height of 105 feet, but two intermediate horizontal struts reduce this into columnar lengths of about 35 feet.

About 14 feet below the top of the end post there is securely attached to it a strong lattice girder 6 feet in depth, which carries the fixed end of the shore span. This girder also serves efficiently to stiffen the top of the post, an arrangement which is both simple and economical. Were it not for the bearing thus afforded to the main girders of the end span, the latter would not only have to be spaced the full width of the main span, but also splayed to correspond. The independent support it affords enables the girders of the end spans to be placed parallel to each other, and at a minimum distance apart. This distance was fixed at 20 feet. The shore ends of the short spans rest upon roller-bearings which allow to the whole structure perfect freedom of movement in a longitudinal direction under variations of temperature.

At the intersection of the end post with the top boom, and the first diagonal tie, a large steel pin is inserted through all the plates which compose these members. The pin is 7 inches in diameter and 7 feet long, its outer ends being held by means of short links attached to the top booms (Figs. 7). To this pin were attached the anchorage-cables during the erection of the bridge, to which reference will be made later.

Erection.

For engineers, the interest which attaches to the execution of this work is due, not to the beauty of the setting, unique though it be, but to the remoteness of the site. This circumstance, however, coupled with a certain degree of ignorance and doubt as to the conditions of life and labour in a newly-opened region (not without suspicion at that time of tropical unhealthiness) constituted a

powerful check to enterprise of the ordinary commercial kind. At the outset it was realized by the engineers that there were many possible risks which would be shunned alike by the British contractor and his workmen; and on the engineers' advice, as far as it was possible to do so, the unknown, doubtful, and incalculable factors were eliminated from the task which contractors were to be invited to undertake.

With the view to induce competition for the steelwork and its erection, the railway-company itself arranged for the transport of the material from a British port to the Zambezi. The company also built workmen's quarters, and undertook the excavation of the rock for the foundations. In this and other ways there were eliminated many uncertain elements which might have made it difficult for a firm at home to prepare an estimate with any certainty as to the relation between cost and the contract-price.

The contract was divided into two parts, namely, first, the construction of the steelwork in the makers' yard and the delivery of it on board ship in a British port; and secondly, the erection of the steelwork on the site. Tenders were invited from British, American, and German firms—the majority of whom ventured only to quote a price for the first part of the work. A few made a close offer for the first part and bid at a venture for the second part. Only two firms, which were British, seemed determined to secure both parts of the contract.

As was to be expected from the completeness of the design and the information laid before the parties tendering, the offers received for the first part of the contract were fairly close; whilst as regards the two firms referred to there was hardly any difference between them. They, however, differed a good deal in their estimate of the cost of erection on the site, or it would be more correct to say, of their proposed plant for that purpose.

Both parts of the contract were let in May, 1903, to the Cleveland Bridge and Engineering Company, of Darlington. It was then anticipated that the construction of the railway up to the Falls would be completed by the end of that year or the beginning of the next, but unexpected difficulties were met with on the route, which caused a delay of 4 months. The rail-head actually reached the site at the end of May, 1904. Until then the transportation of the bridge-material was impossible.

Throughout the preparation of the design the question of erection was considered to be of primary importance, and every detail was devised to simplify the procedure. The arrangement to erect each half of the main girders as a cantilever was not only essential in the circumstances, but was by far the easiest plan, scaffolding being both

impossible and unnecessary. Little difference was required in the scantlings necessary for the arch to provide for the stresses set up by the cantilever.

In designing the details consideration had also to be given to the available means of transport by sea and rail, and particularly to the fact that the parts for one-half of the bridge would have to be conveyed across the great chasm by means of some temporary expedient.

It is true that, 3 or 4 miles above the Falls, the river is passable by means of boats, but this method of transport and communication would have been both tedious and costly, and also not without danger (especially to men crossing in small craft) owing to the current and to the river being infested by hippopotamuses and crocodiles.

Cableway.—At an early stage, therefore, in the laying out of the scheme of operations the idea was conceived of throwing a powerful transporter-cable across the chasm at the site of the works. It was determined also that this apparatus should be provided by the railway-company, and thus an additional facility was offered to contractors. It should be stated, however, that in deciding to separate the cableway from the contract to be let to the bridge-builders, there was another reason besides that of assisting the contractors, and that was the desire on the part of the engineers not to interrupt for a single day the construction of the railway on the far side of the river during the building of the bridge.

With this object in view it was decided to make the cableway of sufficient capacity to transmit over the chasm, not only the material for the construction of the northern half of the bridge, but also the rails, sleepers, locomotives, wagons, and general stores for laying the track on the other side at the average rate of 1 mile, equal to about 200 tons of material, per day.

It having been found that the maximum weight of the component parts of the bridge could reasonably be fixed at 10 tons, this weight was made the measure of the capacity of the cableway, and various slings and cradles were designed for the purpose of carrying steel rails and steel sleepers across in loads of this amount. Although the total tonnage of the bridge-material was small in comparison with that of the railway, and it was foreseen that the cableway would not always be used to its full capacity in the work of erection, but would be in frequent demand for the passage of the staff of the engineers and the railway-contractors and their workmen, etc., it was arranged that the contractors for the bridge should have the operation of the cableway in their hands, and should have the prior right

to its use, it being primarily intended to help in the erection of the bridge.

In July, 1903, tenders were invited for a cableway to span a distance of 870 feet and carry a load of 10 tons net. The conveyor was specified to be capable of lifting and lowering as well as travelling with this load, and to be operated by means of electricity. The idea was to run wagons loaded with bridge-material to a point under the command of the transporting-apparatus.

Among others, a proposal based on Mr. W. F. Brothers's system was submitted. The aim of the designer of this system was to avoid haulage-ropes and to secure a uniform tension on the cable, and so to arrange the supports at both ends of the rope as to enable the load to travel as far as possible from one end of the cableway to the other. In the present instance the cable was designed to be carried on one bank by a steel tower 36 feet high, securely anchored at the rear with guy-ropes, while on the other side the support took the form of a pair of sheer-legs, 80 feet long, set at an angle of 45 degrees, hinged upon pins secured to foundation-plates bedded in concrete. One end of the cable was attached by means of trunnions to the end of the sheer-legs, and a counterweight of 60 tons was supported at the same point. The tension of the cable was thus balanced by the counterweight and was practically uniform in all positions. As the load traversed the cable to the centre of the span the counterweight was raised, and after the load passed the centre it fell, restored to the conveyor the work done, and reduced the power required to drive the load up the incline.

The design at the time was comparatively new, and no apparatus of the kind had hitherto been made on such a large scale. It was therefore regarded—in some quarters—with ill-concealed suspicion.

In effect the principle of the apparatus is that of an overhead travelling crane in a workshop, but instead of running on a solid rail it runs on a wire rope; the driver sits in the travelling carriage, and from there he controls the lifting, lowering, and travelling movements.

The obvious criticism against this proposition duly made its appearance. No man, it was alleged, could be induced, for wages, to occupy the driver's seat and travel all day long to and fro across that awful chasm for months together. Though many troubles were encountered, it may at once be said that this was not one of them.

Because, in principle, it seemed to be right, the system was adopted, but modifications in the plans submitted were made by the engineers. The changes were chiefly connected with the design of the towers, the sheer-legs, and the anchorage. All of these were

subjected by them to careful scrutiny and revision, and in order to guard against any unforeseen defect it was decided before shipment to erect the whole apparatus complete and test it, under a load, in working conditions. As it was chiefly for their use, the design was formally submitted to the contractors for their approval, and it was arranged that they should construct the steel tower and sheer-legs, erect and test the whole apparatus in their works, and re-erect it on the Zambezi.

The precaution of testing the apparatus was justified in the event, for, in the machine tested, the transmission gear—which was composed of friction-wheels—utterly failed, and spur-gearing was ordered to be substituted.

The cable consisted of six strands of nineteen steel wires 0·125 inch in diameter, with a hemp core, the circumference being 8·5 inches, the weight about 5 tons, and the ultimate breaking-stress 270 tons.

For the motive power electricity was determined upon, and sufficient plant was provided to generate current for operating the cranes and riveters and for the lighting of the works. The installation was in duplicate—one-half of the cost being borne by the contractors to provide for their own work. In case either half of the plant failed, the other could be put instantly into service.

The material for the cableway was unloaded at the Zambezi early in June, 1904, considerable delay having occurred in its manufacture and in obtaining delivery out of the hands of the sub-contractors.

In order to get the heavy cable across the chasm, a rocket was shot across carrying the end of a cord, which was in turn used for hauling a wire of sufficient strength to pull across a small rope, which was used for the passage of an extemporized traveller. This latter consisted of a small steel carrier fitted with clips at the bottom to which the main cable was attached; it was then hauled across by means of a winch fixed on the far side and a rope which had been passed over in the way previously described.

On the 28th July, 1904, the apparatus was in working order. Many difficulties, most of them due to inexperience, were encountered in the working of the apparatus. The system of lubrication was defective. The insulation of the motor gave trouble and finally burnt out. This possibility, however, had been foreseen and a spare motor was quickly substituted. The worst trouble, however, occurred with the tires. With the object of minimizing the wear and tear of the cable, they had been made of a soft-natured cast iron. The load on each travelling wheel of the carriage was 7½ tons, and this heavy weight, running on the uneven surface of a cable made of six strands of hard

steel wire, caused an amount of abrasion of the tread which became so serious that doubts were felt whether the apparatus would complete the work. The tires cost £13 per pair, free on board, and the expenses of transit to the site and fitting to the conveyor were very heavy. At one period it was estimated that in tires alone an expense was being incurred at the rate of £1,000 per annum. The method of fixing the tire to the wheel-centre was so defective that several days were lost every time the tires were renewed. It was thought, however, that the wearing-out of the tire was the less of two evils: had they been more durable they might have quickly destroyed the cable. The latter, owing to its hemp core, stretched so much that it had to be shortened and re-fixed.

Towards the end of the work thirty broken wires were discovered in the cable, which represented 13 per cent. of its total strength. It was thereupon decided to reduce the loads of railway-material to 5 tons, so as to minimize the wear and stress and save the rope for the completion of the bridge. A spare rope with a steel core was meanwhile ordered of the same size and strength; and, to make assurance doubly sure, an entirely new travelling carriage was ordered as a stand-by in case of need. In the new machine all the defects discovered in the old one were remedied. The tires were made of more durable material, thicker in the tread, and the method of securing them was much improved. Wrought steel was generally substituted for cast-iron in the frames and bed-plates, thus reducing the weight from 5 to 4 tons and increasing the strength and reliability of the apparatus.

The erection of the steelwork proceeded with great rapidity towards the close, and it happened that the old conveyor just managed to complete the transportation of the bridge-material before giving out, as it did, entirely.

The journey across the gorge in the cradles designed for carrying sleepers was very popular. Occasionally, when the atmosphere was charged with electricity, the conveyor was to be seen in mid-air enveloped in a blaze of lightning.

One of the terms of the contract was the provision of a safety-net. It was specified to be fixed under the points where erection-work was proceeding. Had occasion arisen it might have saved the life of any workman whose hold had relaxed. Many tools and bolts were caught by it, but no man fell. It was kindly intended to give the men confidence, but as it transpired, they complained that it made them feel nervous.

The first work after the completion of the railway up to the site was, of course, the building of the concrete foundations (Figs. 3

and 4, Plate 1), the excavations for which had been previously prepared by the permanent staff of the railway-company. It was in April, 1904, during the progress of this portion of the work, that Mr. C. Beresford Fox had a narrow escape from death by falling down the cliff, and a few months later he had to be invalided home. The size of the excavation on the left bank was small, the rock there being sound, but its position on the face of an almost perpendicular cliff rendered work slow and dangerous. On the right bank it was more easily accessible, but was considerably larger owing to the burden of débris which had to be removed.

The lower part of the concrete was reinforced with old rails, and the upper part with $\frac{3}{4}$-inch steel rods with their ends bent for greater security. The top, for the reception of the base-plate, was strengthened with steel joists 6 inches by $4\frac{1}{2}$ inches by 20 lbs., laid transversely to the joists in the base-plate. Four bolts 3 inches in diameter were inserted in each concrete block for holding down the base-plate. In order to allow for a slight adjustment after the concrete had set, the bolts were fitted into tubes $4\frac{1}{2}$ inches in diameter, the intervening space, after final adjustment had taken place, being filled with cement grout under pressure. Six weeks were allowed to lapse after completion, before any great weight was placed upon it, in order to ensure the setting and hardening of the concrete.

This part of the work, commenced in May, was completed in October, 1904. Meanwhile, the cableway having taken the necessary material over the gorge, work was proceeding in the erection of both the shore spans. At the same time the anchorages for sustaining the main span during its cantilever stage were prepared.

These deserve notice for their simplicity, lightness, and efficiency. Anchorages for similar purposes have usually been carried out by means of a chain composed of heavy and costly steel links and pins, and provided with a formidable adjusting-apparatus in the shape of toggle-gear.

The contractors' engineer in this case, however, devised a system in which comparatively small wire-ropes, easily carried and handled, played the most prominent part. A high quality of steel was used, and each rope was $1\frac{13}{32}$ inch in diameter, spirally laid, 91 ply, and had a breaking stress of 130 tons. Each end of every rope was fitted with an ordinary screw-adjustment, proportionate to its size and strength. The total load to be borne being known, it was only a question of how many ropes would be required and how much of the solid rock in the adjoining ground behind the bridge it was necessary to lay hold of.

On each bank, at a sufficient distance from the edge and in line

with the end posts of the main girder, two shafts were sunk about 30 feet in depth, and a tunnel was driven at the bottom to connect the two shafts.

Each rope of the series employed was attached to the pin, previously mentioned, at the head of the end post, extended shoreward, passed down one shaft, through the tunnel, up the other shaft and thence to the pin on the corresponding end post, to which it was attached in a similar manner by its other end. The rope, in fact, was looped without a knot into the solid rock. The attachment to the 7-inch diameter pin was by means of a U-shaped bolt; the loop end was passed over the pin, while to the other end there was fitted a socket specially constructed and held in place by heavy nuts on the screw-threaded legs, which latter were made extra long for the purpose of adjustment. The wire rope was passed into the socket and fastened in the usual way.

By utilizing wire ropes it was possible to use a very high quality of steel, and by multiplying their number the risk of failure was distributed. Wire rope is cheap, easily transported, and is merchantable when second-hand. Moreover, the larger the number of cables the smaller the load on each, and the easier the adjustment. They can be tuned to carry a uniform stress, or their loading may be compared and adjusted by their deflection. The method adopted compares favourably both in weight and in economy with the system composed of mild-steel links and a toggle-gear adjustment previously mentioned.

The work of erecting the steelwork actually began in August, 1904, and the most difficult and slowest part of it proved to be the operations of fixing the shore spans and connecting them with the end posts of the main girders. The ends of the shore spans were let into recesses cut out of the rock and anchored by their upper corners. They were built out a certain distance as cantilevers, and at a further stage supported by scaffolding fixed on the slope of the cliff. As soon as the end post of the main span was up, the shore span connected with it and the anchorage coupled, a stable platform was obtained and the rest was easy and expeditious work.

Specially designed cranes with two arms, each commanding a radius of 30 feet and able to revolve in an arc of nearly 180° were promptly placed on the top of the completed portion of the work and pushed forward as far as possible. They were actuated electrically, were capable of lifting 10 tons, and were arranged to stand on the cross girders as and when the latter were fixed. This stage was reached on the right bank early in December, 1904, and on the left bank during the last days of the same month.

The first panels, being the largest and containing the most material, naturally occupied the longest time, 2 to 3 weeks; but this was gradually reduced until at the centre, eight posts and their fellow-members were placed in position in 26 days, the work, of course, being done simultaneously from both sides of the river, so that each panel occupied 6 days in erection; and this rapidity was attained in spite of delay caused by the delivery of the material failing to keep pace with the progress of the erection, which constitutes fair testimony not only to the efficiency of the design, but also to the precision achieved in the workmanship.

The work of erection was undoubtedly facilitated by two features of the design. First, by the pin (Figs. 10, Plate 2), previously referred to, whereby the connection between the various members at the point of intersection could be instantly made, and work allowed to proceed in advance of the riveting; and secondly, by the placing of the joints in the chord members in advance of the vertical posts, so that the cross girders could be placed in position as soon as the posts were secured.

The cantilever arms met in mid-air on the 1st April, 1905, that is, less than 4 months after the erection of the end posts.

Although it had been the aim of the engineers to do it in the dry months of the year 1904, and thus avoid the climatic period fraught with risk to the health of fresh-blooded Europeans, it is interesting to note that, owing to various delays, the work was done in the following rainy season and that no serious harm ensued. The rains begin in October and end in May. The worst rainy months are March and April. In addition to rain the bridge is wetted by the spray from the falls, which is, of course, influenced by the height of the columns of spray, which in the rainy season rise to 3,000 feet, and also by the direction of the wind. It is not any worse than the rain, say, in Scotland, and for 5 months of the year it does not touch the bridge at all. The spray is heaviest in the months of March, April, and May.

General.

Materials.—With few exceptions the bridge is constructed of rolled steel manufactured in England by the Siemens open-hearth acid process. All the plates and the principal angles were made by the Consett Iron Company, Durham. Material and workmanship were subjected to rigid inspection and proved to be of uniformly high character. The breaking stress of the tested pieces averaged 29·6

tons per square inch, the elongation being 24·6 per cent. in 8 inches, and the limit of elasticity 60 per cent., all within a 2 per cent. margin of variation. The exceptions referred to consisted of steel forgings. No cast iron or cast steel was employed in the work.

The concrete was specified to be made of 3 parts of broken stone and 2 parts of sand to 1 of Portland cement. The latter was sent from London packed in iron drums, and reached its destination in good condition.

Painting.—The question of the preservation of the steelwork was felt to be of the first importance, especially as some parts of the structure, such as the wind bracing, are comparatively slight.

The work was designed with a view to its shedding moisture, and not retaining it, and every part was made easily accessible and open to inspection. All the parts were treated in a manner to defer corrosion as long as possible, and, when it should occur, to disclose it and enable its further progress to be arrested.

After a thorough cleansing and treatment with red-lead and linseed-oil (ascertained to be pure in quality), both before shipment and after erection, the steelwork was covered with three coats of Torbay paint of a specially selected silver-grey colour. This particular shade was chosen because a patch of rust in it will appear conspicuous by contrast. It has the further advantage of absorbing little of the heat of the sun. Thus painted, the steelwork, a year and a half after completion, was reported to be in very good condition, and to respond slowly to changes of temperature.

The colour harmonizes well with the surroundings of the bridge, though the appearance of the landscape changes considerably with the seasons. Care will of course have to be taken to maintain the bridge in good condition, but this will not be so difficult and costly a matter as might be supposed.

On his visit to the works in July, 1905, when all the steelwork but the riveting was finished, the Author was gratified to find the native workmen engaged in the work of painting, all over the bridge. This is the more remarkable because until the advent of the railway there were no natives living within 60 miles of the falls owing to their superstitious dread of the locality.

It is a remarkable fact that wind is experienced only to the slightest extent in this locality. Very light temporary buildings placed at the most exposed points stood unshaken. The bridge is situated in a sheltered position, so that should a strong gale ever arise it is unlikely that the structure could feel its full force. On the 4th November, 1905, observations were taken of the bridge during the passing of a train headed by two locomotives and weighing 612 tons

(the heaviest load obtainable), running at 15 miles per hour elastic deflection at the crown was 0·84 inch, the deflection the same load when stationary being 0·5 inch. The bridge vi laterally with a frequency of 70 per minute, and an amplitude middle of the bridge of 0·5 inch for 15 seconds after the pas the train.

No fatalities from fever or sickness occurred. One fatal ac happened to a white man, and one native was killed at the time, but in a manner that was culpable and might have oc in the safest place, and was not due in any way to the nature work or the place.

Quantities and Cost.—The quantities of the steelwork in the are approximately as follows:—

	Arch.	End Spans.
Main girders	1,010 tons.	65 tons.
Cross girders	70 „	19 „
Deck, rail-bearers and parapet	123 „	37 „
Lateral bracing	145 „	10 „
Bearings	55 „	5 „

The weight of the bearings in detail is as follows:—

Bearing-pin	1·06 tons each.
Pedestal	2·63 „
Base-plate	4·50 „
Springer	3·20 „

The cost of the work was approximately as under:—

	£
Steelwork	21,000
Transport	12,700
Erection	27,000
Cableway	4,000
Spare rope, conveyor and tires	750
Excavations, exclusive of railway cutting, about	6,550
	£72,000

The bridge was constructed to designs and specifications pre by the Author's firm, Sir Douglas Fox and Partners and Sir C Metcalfe, Bart., MM. Inst. C.E., Engineers-in-Chief of the Rh Railways. The Author desires to express his appreciation c able assistance rendered by Mr. Ralph Freeman in the calcul and drawings. Sir Charles Metcalfe generally superintende work on the spot; Mr. S. F. Townsend, the Company's Resident Engineer, was in charge of the construction o

railway and the bridge; Mr. William Tower, M. Inst. C.E., was Resident Engineer on the bridge-works, and during the excavation of the foundations was assisted by Mr. Charles Beresford Fox, Assoc. M. Inst. C.E. Mr. J. W. Chatterton rendered valuable service as inspector during the erection of the bridge. The Contractors, The Cleveland Bridge and Engineering Company, of Darlington, were represented by Mr. Georges C. Imbault, who acted as their agent and engineer.

The Paper is accompanied by nine tracings, one photo-print and one drawing from which Plates 1 and 2 and the Figure in the text have been prepared.

Discussion.

The President. The PRESIDENT, in moving a vote of thanks to the Author, thought the members would agree that it was of the greatest advantage for The Institution to have had so complete and interesting an account of this great work contributed to its Proceedings.

The Author. The AUTHOR exhibited a series of lantern-slides illustrative of the work, and in describing one showing the closing of the arch, he mentioned that the two centre panels of the arch were fixed about sunset on the 31st March, 4 months after the end posts had been erected, and it was found that the panels overlapped to the extent of about 1¼ inch. The steel truss had been exposed the whole of the day to the heat of the tropical sun and had elongated. When work was begun at sunrise next morning, it was found that it had contracted in the night to the extent of 1¼ inch.

Sir Douglas Fox. Sir DOUGLAS FOX, Past-President, felt that on this occasion he had little right to be heard, the credit for the design resting with his partner, Mr. Hobson, ably assisted, as he had been in the details, by Mr. Ralph Freeman. He thought, however, something should be said about those who had had charge of the erection at the site, a long way from those who had had the responsible charge at home. The effective carrying-out of the work had depended very much on their coolness and courage. The firm of Contractors who undertook the work had faced it in the most creditable manner, and the members had heard of the extraordinary speed which they had attained. Great economy had resulted from their excellent temporary arrangements, for which the chief credit rested with a young French engineer on their staff, Mr. Imbault, who had had charge of the designing of the Contractors' plant and had carried out the Engineers' specification in the most complete way. Under the control of their excellent Resident Engineer, Mr. Townsend, and his staff, the work had gone on without any difficulty or friction, and as the lantern-slides had shown, it was by no means easy. To his nephew, Mr. C. Beresford Fox, belonged the credit of having been the first person to cross the gorge on the temporary rope. He thought the design was a masterpiece on the part of the Author, but credit was also due to those who had carried out the work, and he was very glad to say thus a few words in praise of those who had so thoroughly carried out the intention of the Engineers. He wished to say a word also about his partner Sir Charles Metcalfe, by whom the site of the

bridge had been fixed. Sir Charles had taken a great deal of personal trouble about it, and the point he had dealt with most effectively was that the bridge should be so placed as not in any way to interfere with the amenities of the Falls. Sir Douglas had heard from people who went there with the British Association, and from others, that this bridge was actually an ornament to the scene. Sir Douglas Fox.

Mr. ALEXANDER SIEMENS had nothing to say with regard to the work, but wished to tell a short story. He had had the pleasure of visiting the bridge when in Africa with the British Association, and he had been told that a chief of the Barotse, one of the neighbouring tribes, came almost daily and sat down and watched the building of the bridge. He said it was impossible that a small thing like that could carry anything—that it would be dangerous to walk over it. When it was completed, and he found that a train could go over it, he said it was the finger of God that kept it up. Mr. Siemens.

Mr. ERNEST BENEDICT asked in what way the span had been measured, how the deflection had been ascertained, and how the expansion-joints in the rails had been managed. He also desired to know in what capacity the natives had been employed besides painting the bridge. His experience had been that under skilful guidance the natives could be trained to do almost any kind of work, and it would be interesting to hear if they had been employed in riveting and other work. Mr. Benedict.

Professor E. G. COKER wished to know if the device of putting in the small pin before the riveting took place was entirely new. In pin-connected bridges there was of course no need of such a device, and in all the riveted bridges he had examined no such device had been used. It appeared to him to be a new and valuable aid in erection. With regard to the method of calculation, the Author gave the formula $\frac{300}{500 + L}$, where L was the loaded length producing the maximum stress. On looking at this bridge he had at once thought of the one over the Niagara Gorge just above the rapids, which, although of different dimensions, was very much like the bridge over the Victoria Falls in many respects. He had tried to find out what impact-formula was used in the Niagara bridge, but had not succeeded in doing so. Seeing, however, that it had been built by the Pennsylvania Steel Company the probability was that the formula was not very different from $\frac{300}{300 + L}$, which was the common formula of the American Bridge Company. He wished to know why a different impact-formula had been taken for the Victoria Falls Prof. Coker.

Prof. Coker. bridge. On working it out he found that it caused a difference, varying from 66 per cent. when L = 0, to 33 per cent. when L = 300, in the stresses to be added for the impact effect of the live load. As there was so much difference between the formula used by American engineers and that used in the present case, he thought that the unit-stresses for the members might be very different, but he found that was not so. The tensile stress was roughly 18,000 lbs. per square inch, whereas in the American Bridge Company's practice it was 17,000 lbs. In Mr. Waddell's practice, given in his pocket-book,[1] it was 18,000 lbs. for eye-bars, and 16,000 lbs. for shapes. The same thing seemed to hold good for the compressive stress. This stress was not stated in the Paper, and a comparison could not be made, as the allowance for the length of the member was not given, but he presumed it was not very different from what was current practice with American engineers. He noticed that the wind-load on the bridge was very light, and that would perhaps account for some of the difference. He would like to know whether the wind-load had been calculated as a moving or as a fixed load.

Mr. Read. Mr. R. J. G. Read thought that the designers had succeeded very well in taking appearance into account in the design. As the bridge was the only crossing over the river for a very long distance, it would be interesting to know whether a roadway could not have been carried over the river on the same bridge, as in the case of the Niagara Falls bridge. The Author admitted that a mistake was made in the foundations of the abutments on one side, on account of which the bridge had had to be lowered from the position intended. Criticism on that point was disarmed, but from the section it seemed that the bridge would have looked more comfortable if it had been set farther back into the cliff on the left-hand side. Owing to the lowering of the bridge, the line had to run in a cutting on each side, and probably the view of the falls had been obstructed to some extent. The cross girders carrying the floor were placed along the top chord, at and between the intersections of the bracings. This brought a secondary stress upon the top member which was said to be provided for; but it seemed that the intermediate cross girder might have been omitted, and the cross girders rested on the intersection of the bracing. The girders would have had to be a little deeper, and that would have raised the roadway higher. The anchoring by wire-ropes during erection was an ingenious and simple method, but

[1] J. A. L. Waddell, "De Pontibus: a Pocket-Book for Bridge Engineers." New York, 1898.

he would like to know whether, in the attachment of the ropes, any provision had been made for adjusting the level of the structure, as was practicable when toggle-joints were used. The safety-net seemed, from the lantern-slides, to have been hung too far down; it might have been hung closer up under the work. He could quite bear out the feelings of the men. In supervising the erection of the Blackpool tower, he had felt nervous in getting about during the early stages, but when the tower reached a height of 500 feet he felt no nervousness whatever. Mr. Eiffel had found the same sort of thing in the erection of the Eiffel tower. It was merely a matter of use, and no doubt when the men reached the middle of the Victoria Falls bridge they had become accustomed to the work and had no fear. Mr. Read.

The PRESIDENT observed that when a Paper described a piece of work of such magnitude, interest, and difficulty, the description itself was generally the chief point in the proceedings. It was not expected that such a work would raise any considerable discussion, and perhaps it might be said that the interest of it was inversely as the square of the length of the discussion. He hoped, therefore, the Author would not think the Paper was not highly appreciated because the discussion happened to be short. He wished to say one word on his own account, especially after the remarks of Sir Douglas Fox. In his Presidential Address he had remarked upon the appearance of engineering structures, and he was delighted now to see that the Paper pointed the moral of his Presidential remarks admirably by describing a work which was everything that an engineering structure, from the point of external appearance, ought to be. It was very striking to notice the difference between the first two lantern-slides of the gorge, before the bridge was erected, and several of the later ones, where the structure was shown complete. The lines of the structure, themselves quite beautiful, brought out at once the vastness of the gorge itself, which without the structure could not be realized. Before the bridge was built the gorge was something very beautiful but quite indefinite, but directly that beautiful arch was put up it gave an entirely new interest to the landscape. He did not think anybody who had seen the Victoria Falls bridge would ever find fault with the engineers who designed it. The President.

The AUTHOR, in reply, observed that the bridge, though not one of the first magnitude, ranked among the largest of its kind. Compared, however, with the great cantilever and suspension bridges of the world it was of only moderate span and capacity. A good deal of interest attached to the work owing to its situation on the confines of the Empire, and on a recent extension of the frontier. The claim had been made (though not by the engineers) that it was the The Author.

The Author. highest in existence. Whether that was so or not was of no engineering importance. It was certainly one of the loftiest as regarded the height of the railway-track above the water it crossed. Measured from low-water level, the height to the rail-level was equal to the height of St. Paul's Cathedral from floor to pinnacle. The impact-formula used in the calculation of the stresses had no connection with the formula $\frac{300}{300 + L}$ recommended by the Government of India and by certain American bridge-designers. It merely happened to take the same form. The method of allowing for impact in the Niagara Falls bridge was a conspicuous feature in the Paper[1] on the subject in the Transactions of the American Society of Civil Engineers (the only authoritative description of this bridge) and was totally different. It consisted in the adoption of lower working-stresses for live loads than for dead loads. Hence, the comparison which Professor Coker had made did not apply in reference to his remarks about American practice. Rules for impact were empirical and subject to the judgment of the engineer: they were not universally applicable. Two radical differences between the conditions under which the Victoria Falls and Niagara Falls bridges had been designed needed only to be pointed out. In the former the mild structural steel used had an average breaking-strength of 30 tons per square inch, and the bridge was subjected to an infrequent load—one or two trains per day—while in the latter the steel used presumably conformed to the usual American practice and had an average strength of 27½ tons per square inch, and had to carry a frequent service of some of the heaviest trains in the world. The quality of the steel used and the working-stresses of the Victoria Falls bridge were given in the Paper. In calculating the maximum stresses the wind load had been treated half as a fixed load and half as a moving load. The pressures assumed were by no means low. On the contrary, for so large a structure they were excessive, and would not have been used except to ensure sufficient lateral stability in the wind bracing and at the centre of the bridge. No wind-stresses whatever were allowed for in the members of the main trusses of the Niagara Falls bridge. In setting out the bridge the span had been measured in the first place by triangulation, and finally by direct measurement with wire. A wire was set up along a measured length of 500 feet on level ground on the bank, secured at one end and subjected to a known tension at the other; it was then marked to correspond with

[1] R. S. Buck, "The Niagara Railway Arch." Trans. Am. Soc. C.E., vol. xl (1898), p. 125.

the measured length of 500 feet. The wire was then used to measure the span direct, being subjected to the same tension. So long as this tension remained constant the straight length between the marks was 500 feet and was independent of the deflection, whether such deflection was due to the weight of the wire or to wind-pressure upon it. To ensure accuracy the measurement was repeated with different wires. Regarding the device of the setting-pin, the Author did not think that it was new, though he did not recollect where it had been used in precisely the same way. It was an excellent system for ensuring accuracy, and greatly facilitated erection. The method of adjusting the anchor-cables by means of screws on the U bolts was mentioned in the Paper. The system had worked perfectly and a further fine adjustment, of a much more delicate character than could be possible with toggle-gear, had been obtained by weighting the wire ropes with rails. A large range of adjustment, ample for all emergencies, was obtainable by the means adopted. The net provided for the safety of the men had been slung on wire ropes stretched taut right across the gorge at the springing-level, and as close up to the arch as possible. As the work had advanced the net had been moved *pari passu*, and so the distance from the underside of the arch had increased until the centre was reached; and no doubt on this account the contrivance had become less efficient for the purpose intended. Fortunately it had never been called into requisition. To provide a perfect safety apparatus would have been a costly and complicated matter. No special provision was made in the rails themselves for expansion and contraction. Each rail-joint allowed for a movement of $\frac{1}{4}$ inch, and the rails were so fastened to the steelwork that they could move longitudinally, any tendency to lift being restrained. No difficulty had arisen with regard to the expansion of the rails, which apparently accommodated themselves to changes of temperature. The reasons for using the type of deck chosen were partly given in the Paper. The provision of a roadway would have added considerably to the weight and cost of the structure. Nor was it desirable, from the railway-company's point of view, to provide a roadway: on the contrary, it was to their interest not to allow it. The traffic was mostly long-distance traffic—the local business was practically negligible—and all could be well served by the railway. This great work had been constructed at vast expense, and it would have been foolish to afford facilities to trekkers in a region where control was impossible, or at least prohibitive in cost. Few portions of the work had given more cause for thought than the deck. Owing to there being no need of a roadway for vehicular traffic, and for other obvious reasons, a timber platform The Author.

The Author. had been adopted, laid between the railway-tracks—which, except the way-beams, were of course entirely of steel—and between them and the parapet. This had seemed to be the simplest and most economical plan, and to provide a comfortable surface to walk upon. The alternative of a steel-plated floor had been rejected as being heavy and costly, besides exposing to corrosion a large area of comparatively thin metal, offering a large under-surface whereon moisture could condense, and impeding at the same time the free circulation of air. With the exception of the railway-tracks, therefore, the deck was formed of carefully selected pine timber, 3 inches thick, laid in 9-inch planks with air-spaces $\frac{1}{8}$ inch wide. To preserve it from the rain and spray the timber had been thoroughly creosoted; while to shield it from the heat of the sun and from the danger of fire liable to be caused by burning cinders, it had been covered with a thick coat of Stockholm tar and strewn with sand and fine gravel. The result had been disappointing. The fierce heat of the sun and the extreme dryness of the atmosphere in the winter months had distilled the creosote and the tar and thereby released the sandy covering, which had been gradually wafted away. Rigid injunctions against raking out ashes on or near the bridge were now therefore issued to engine-drivers and a watchman was stationed to inspect the deck after the passing of each train. As, however, half the trains which crossed the bridge passed in the night, and the neighbourhood was infested with lions, leopards, and many varieties of wild cat which might make the deck their noctural promenade (a fine leopard was killed by an engine on the bridge shortly after the track was laid), it was evident that protective measures independent of human agency must sooner or later be adopted, and these were under consideration. Meanwhile the timber was receiving attention, and a coat of cement was being applied to it. The employment of natives in the work of erection was a matter worthy of notice. The African native was superstitious and did not usually take risks if he could avoid them, but let the white man give him a lead, and he would go anywhere and attempt almost anything. All the innovations introduced by civilization were to him but the white man's magic, and he accepted the marvels of science and art with calmness and resignation. Some of those employed had come from remote parts of the interior and were quite wild, others were from Nyassa and from the southern colonies and were trained in various degrees. The former had been paid 10*s.*, and the latter up to £3 per mensem, and all had been supplied with food and housed in suitable style. As many as 400 had been employed at one period and the average number was about

200. In addition to assisting skilled whites, of whom about 30 had been employed in erecting the steelwork, they had done good service in excavating the rock and in painting. Being imitative and patient they became skilful and reliable painters, capable of working in highly dangerous positions and in a very thorough manner. The natives had done no actual riveting, but all the heating and passing of the rivets had been done by them. He regretted that the discussion had not dealt with the important question of the preservation of steelwork, both generally and with special reference to the present case. The maintenance of the Victoria Falls bridge presented an interesting problem for solution. Its circumstances were unusual and severe, and a sad comment was afforded on the present known means for the prevention of corrosion by the fact that the Author, whose experience on the subject was long and wide, should have fallen back on a very old-fashioned method rather than trust to any modern nostrums. The subject was one of such vast interest that he was of opinion that it was worth the serious consideration of The Institution and of the Engineering Standards Committee. The fact of the bridge being approached in a cutting had made no difference to the view from the line, for owing to intervening ground and forest the Falls could not in any case be seen from the railway except during the crossing of the gorge. Regarding the appearance of the bridge the Author desired to express his appreciation of the remarks made by the President thereon. It was the lot of engineers occasionally to be charged with perpetrating acts of vandalism, and the engineers in the present instance had not escaped the attacks of those highly aesthetic people who asserted that utilitarian works of man should not be permitted to exist in the presence of scenery famous for its natural beauty. It was sometimes possible to sympathize with these views, but, on the other hand, even a railway-bridge need not necessarily spoil; it might even add a charm to a beautiful spot, and a line of metals might give considerable interest to a grand scene without the least detriment. The scenery of the Victoria Falls ranked among the finest in the world, and the Author thought it would be a disgraceful act on the part of anybody to erect any structure which would interfere with or detract from its marvellous beauty. Speaking for his partners and himself, he desired to place this opinion on record, in order that, while they had the charge of operations in that region, they might live up to it and also set an example to their successors. He was encouraged to think, from the remarks of the President and from the fact that adverse criticism had long been silent, that the subject of the Paper had not sinned in this respect. Of course, during the The Author.

The Author. construction of engineering works of any magnitude it was impossible to avoid creating some unsightliness and disorder in the vicinity. Such had been the case at the Victoria Falls, and doubtless it had caused adverse comment, but after the work was finished and the temporary shanties were removed, nature rapidly restored order and covered all unsightliness. In a tropical country a single wet season completely obliterated all traces of human labour except the permanent structure itself.

Correspondence.

Mr. Breithaupt. Mr. W. H. Breithaupt observed that the account of the mistake made in the examination of the bridge-site was instructive. A similar occurrence had come under his observation some years ago. The under-water examination of a bridge-site showed bed-rock, mostly at considerable depth. Toward one bank of the river a large boulder was taken for bed-rock, and the supposed ease of foundation at this point determined the design. The error was not discovered until the foundation-caisson was sunk to the boulder: it entailed practically a year's delay in completion of the bridge, and very considerable increase in cost. In the present instance the consequence was a change of gradient by 21 feet, which in most cases would be serious or impracticable. For rigidity, ease of erection, and dignity of appearance, the spandrel-braced, two-hinged arch was perhaps the best solution of the problem. The objections to it were the large reversals of stress, and ambiguity, especially in temperature-stresses. In the Niagara arch, which had been very carefully considered, a material addition had been made for this ambiguity. The large reversal of stress to which especially some of the chord-members and some diagonals were subjected in the structure rendered the proportioning of sections indefinite. Molecular changes of the material were greater, to an indefinitely-known extent, under reversals than under fixed stress, or stress of the same kind as to compression or tension. There could not be said to be any finally accepted section-proportioning for large reversals or even for great differences between maximum and minimum stresses of the same kind. Reversals were more objectionable still at joints, as continuity of the material was here necessarily more or less broken. Permanent structures should preferably not have reversed stresses. It might be argued that railway-bridges, particularly in America, were not permanent structures, in that loads for which they were

designed increased so rapidly—they had almost doubled in 20 years —that a structure had to be taken down long before it had any opportunity to show deterioration of material, as based on its proper load. The cost of erection per ton appeared to have been greater than at Niagara, which was justifiable if the much smaller weights (total weights less than one-half, and sections much lighter, with span-length varying proportionally little), the distance from shops, and the difficulty of getting skilled workmen were considered. At Niagara, on the other hand, the new bridge replaced an old one, occupying the same site, and carrying a traffic averaging four trains per hour. The erection-anchorages were to be commended for their simplicity, and for the use in them of material afterwards easily disposable. With the anchorages used, however, control of the ends of the arch as to raising or lowering would have been a complicated undertaking. Mr. Breithaupt.

Mr. L. L. Buck observed that his bridge over Niagara River was, in some respects, strikingly similar in principle to the Victoria Falls bridge, although the Niagara bridge was, in every respect, a much longer and heavier structure. It was a double-deck bridge, carrying on the upper floor two tracks of 4-foot 8½-inch gauge, with a load of 3,500 lbs. per lineal foot on each track, besides the extra load due to locomotives. The lower floor for ordinary horse-vehicles, foot-passengers and trolley-cars was calculated for a load of 3,000 lbs. per lineal foot of bridge. Otherwise the arch was very similar in principle. The two-hinged structure, where the arch was not too flat to allow of its use, was by all means preferable to the three-hinged, as being stiffer and not so liable to vibrate either vertically or laterally. Indeed he would feel that considerable increase in weight of structure on this account would pay. In thinking of the Niagara bridge since, he had regretted not having adopted the plan of boring a pin-hole at the intersection of the axis of the chord and web members and putting in a turned pin to locate the members properly while erecting, and then driving the rivets afterwards, as it would ensure greater accuracy, and agree better with the calculations. Still, the bridge had come out fairly well. In the test of deflection only 2,400 tons could be got on both tracks wholly on the arch portion. The two trains moved on abreast from one end, stopping at one-quarter, one-half, three-quarters, and the whole span, levels being taken at every panel-point for each position of the train. The maximum deflection, at the crown, was only $\frac{13}{16}$ inch. He did not understand the method used in anchoring the portions on each half of the arch of the Victoria Falls bridge. He had designed the Niagara anchorage to be safe, and felt that it was safe and as economical as the circumstances would allow. Mr. Buck.

Mr. Doak. Mr. W. J. Doak remarked that while it was very probable that the spandrel-braced arch was the most suitable design for this bridge, principally on account of economy and convenience in erection, it appeared that the beauty and economy of it might have been considerably improved by increasing the panel-length to say 31 feet 3 inches. The very steep angle of the long diagonals near the ends did not conduce to elegance, and gave an impression of wasteful design. It was stated by the Author that the spacing of the cross girders was in a large measure governed by the Rhodesia Railway standard rail-bearers. It was perhaps a pity to allow such an unsuitable standard much weight in designing this important bridge. Although the dimensions of rail-bearers and cross girders were not given, it was sufficiently obvious that a considerable saving in weight and time could have been got by the adoption of an American type of deck, consisting of timber cross ties laid on steel longitudinals, strong enough to span the 25 feet between panel-points. The number of cross girders would thereby have been reduced by one-half, and the undesirable bending-stresses in the top chord, caused by the intermediate cross girders, would have been avoided. He believed that the principal advantage claimed for the trough form of rail-bearer was that in case of derailment the wheels would run in the trough, and the bridge would be saved from destruction; but the provision of guard-rails between the running-rails met this emergency satisfactorily. In Queensland a derailment had been known to occur on a timber trestle, and although the wheels were small and the space between ties about 18 inches, no serious damage had been done. Experience in that State had shown that the dog-spikes split the longitudinal timber, which was moreover an awkward piece to renew. It would be interesting to know how the rule for converting live-load into equivalent dead-load stresses had been arrived at. Assuming the stress 538 tons in A U (p. 5) was caused by a train on the whole span, the increment for impact in this member would by this rule be 30 per cent., which seemed a liberal allowance. The statement that the steel was subjected to 7 tons in compression was a surprising one in view of the long lengths of many of the columns. He had found that the most consistent results were to be got by using formulas based on the French rule $S = f\left(1 + \frac{1}{2}\frac{\text{min}}{\text{max}}\right)$ for all tension-members, and $S = f\left(1 + \frac{1}{2}\frac{\text{min}}{\text{max}}\right)\left(1 - k\frac{l}{r}\right)$ for all compression-members. Perhaps the Author would say what types of riveting-machines had been found most suitable, and whether observation had been taken to

compare actual temperature-changes with those allowed for. He would like to express admiration for the ingenious and simple method of anchoring the girders during construction and also for the useful idea of the small pins at intersections. A few sketches of the conveyor would have enhanced the value of this very interesting Paper. Mr. Doak.

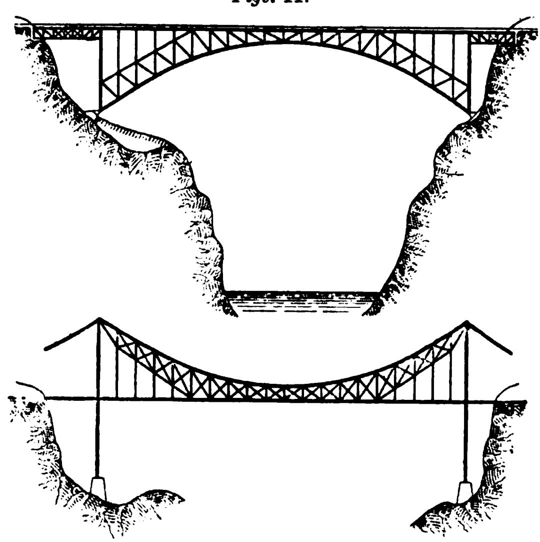
Mr. GEORGE L. HUNTER desired to ask the Author the following questions:—What was the total weight of material carried by the cable? How long was the cableway in operation? Was the stretch of the cable really due to "stretch" in the usual acceptation of the term, or was it natural extension due to the expansion under the high temperature to which it was exposed? If stretch really did take place to an abnormal extent, were careful measurements taken as to the reduced circumference of the rope? What was the total elongation? With regard to the trouble of the wear of the tires, his firm, Messrs. Thos. and Wm. Smith, who made the cable, strongly advised the adoption of a hard cylinder-metal for the cast iron in these. Apparently they were of a soft mixture. Mr. Hunter.

Professor W. C. KERNOT remarked that the general design appeared judicious from the point of view of both erection and subsequent use. The two-hinged arch was probably, on the whole, better than the three-hinged, provided proper precautions were taken in construction. The end spans appeared to be needlessly long, and simple plate-girders would probably have been cheaper for them and also for the "bearing-girder" in Figs. 6, Plate 2. This latter seemed very complicated. The object of reinforcement in the concrete in Fig. 4, Plate 1, so close to the rock foundation was not clear. Surely there could be no transverse stresses or tensions within 3 feet of the solid rock. It was not stated whether any account was taken of "secondary" stresses due to the fact that the junctions were rigidly fixed and not frictionless hinges as assumed in ordinary theories. The assumption that half the wind-pressure passed along the upper wind-bracing and half down the verticals to the arch appeared to be somewhat rough and uncertain. Could not a more definite calculation be made? It would have been very interesting and not specially difficult to apply extensometers to the arches near the springing and at the crown, and also to the principal verticals of the spandrel-bracing, and to read them before and after the riveting up of the centre joint in the top member, as well as before and during the application of the test-load. The results, by their correspondence with calculation, would strengthen confidence in the mode of calculation adopted. Such field-extensometry had been largely used on railway-bridges in Victoria, and the results had proved interesting and valuable. Prof. Kernot.

Mr. Lindenthal.

Mr. GUSTAV LINDENTHAL considered that when the span of the spandrel-braced arch, which was the form of arch used for the Victoria Falls bridge, exceeded 500 feet, the members at both ends became of inconvenient length. For such longer spans, a form of arch commended itself which was shown in *Figs. 11*, and which could be appropriately termed "half spandrel-braced": that was, instead of the chord being continued in a straight line, it was deflected at the quarters to run quasi-parallel with the rib to the abutment. The advantage of this form was that the diagonal web-members throughout were kept reasonably short, and it gave the greatest depth of web at each quarter of the arch where the

Figs. 11.



greatest bending-moments from live load occurred. This form of arch was specially adapted to long spans. In a 1,000-foot spandrel-braced arch, for instance, the end members would be 150 to 200 feet long, depending upon the rise of the arch. With the half-spandrel-braced arch, web members near the abutments could be kept down to a length of 30 to 50 feet. For short spans, the half-spandrel-braced arch did not show any economy, as compared with the full spandrel-braced rib. But for longer spans the economy became more marked, because the temperature-stresses were less and the material required for all the members, except the rib, was less than for the same members of the full spandrel-braced rib, as

shown by comparative calculations which he had made. When the depth of web at the quarters of the arch was chosen a little larger than one-quarter of the rise of the arch, then no increase in the sections of the rib was necessary for the stresses from partial live loads, beyond those required for a uniform full live load. This form of arch was also suitable for suspension-bridges and would compare favourably in point of economy and rigidity with cantilever-bridges up to 2,000 feet span. Although the Victoria Falls bridge was similar to, though smaller than, the Niagara Grand Trunk Railroad bridge, and hence did not offer any essentially new features for discussion, yet there was one detail in which the two differed importantly, namely, the arch-bearings. The Niagara bridge had segmental roller-bearings and the Victoria Falls bridge had pin-bearings. There was little doubt that the latter were preferable, as being less subject to corrosion, which unavoidably would prevent the rollers from turning and from performing their proper functions. It was not contended that the pin-bearings permitted turning motion on the pin, because no such thing had ever been observed; but the variations in the direction of pressure were kept within far narrower limits than with corroded roller-bearings. Mr. Lindenthal.

Mr. Frank W. Skinner remarked that the Victoria Falls bridge was notable for the greatest combined span and height of any similar structure yet built, and afforded an example of brilliant engineering skill in design, construction, and erection. It was a thoroughly up-to-date structure, and included features of the best and most advanced practice in Europe and America. The simplicity, rapidity, economy, and safety of the construction could not be too much commended, and reflected the highest credit on the engineers and contractors in charge; the description of the structure could hardly be improved except to be extended. The selection of the two-hinged spandrel-braced arch-truss instead of a three-hinged arch was undoubtedly in line with the best engineering judgment, and the structure was evidently admirably adapted to the conditions at the site. The general design of members, and the details of connections appeared, as well as could be judged from the few illustrations accompanying the Paper, to be excellent, and it was gratifying to American engineers to note that they, as well as the methods of erection, conformed very closely to American practice. Among the most noticeable points of excellence were the location of the chord-joints beyond the panel-points, thus simplifying truss-connections, and facilitating erection; the use of pin-connections for erection; the elimination of oblique or complicated connections at all panel-points except at the skew-backs; and the adoption of Mr. Skinner.

Mr. Skinner. riveted instead of cast-steel pedestals and bolsters—an advantage notably demonstrated in a comparison of the two longest spans now under construction in the world—the 1,800-foot four-track Quebec bridge, and the 1,182-foot span of the six-track Blackwell's Island bridge. In the former case the pedestals, bolsters, and other parts of each bearing had an assembled weight of 565,000 lbs., transmitted a maximum load of 28,000,000 lbs. to the pier masonry, and were made entirely of riveted members connected by a 24-inch pin. The pedestal (the largest separate piece) weighed 156,000 lbs. and was transported on a special car, and required materials up to the maximum capacity of the rolling-mills and machinery. The reliability of these bearings could not be questioned, and they had been easily made to time, and delivered without delay. In the Blackwell's Island bridge the heaviest pedestals weighed about 260,000 lbs., had a 23,770,000-lb. maximum load, and were made of four cast-steel sections, the heaviest weighing 72,000 lbs. Great difficulty had been experienced in casting them satisfactorily, and several months' delay had been occasioned, hindering the erection of the whole structure and causing considerable damage. The method of grouting the masonry bearings and setting the anchor-bolts in adjustable casings was excellent, and eliminated serious doubts regarding the satisfactory use of lead plates or compressible fabrics for such purposes. He thought it would have been better to increase the size of the panel-point pins and eliminate the rivets at main connections, thus changing the truss from a riveted to a pin-connected one; that the inclination from the vertical of the end diagonal members in the trusses should have been increased to a more economical angle; that the bottom lateral system should have been made without secondary struts; and that the truss bearing on the skew-back hinge-pin should have been a single-riveted piece with a cast-steel saddle. This was the most vital connection in the structure, and should be entirely of riveted rolled steel. Such a detail might be somewhat more difficult to make than the one here used, but that it was entirely practicable was demonstrated by the bearing for the similar 416-foot span of the Driving Park Avenue bridge, at Rochester, N.Y.[1] Even this might be improved by making a gusset-plate connection instead of a flat bearing for the end post. In view of the statement that the structure was exposed very little to winds, it appeared that the assumed wind-pressures were taken much too high. As all truss

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[1] See F. W. Skinner, "Types and Details of Bridge Construction," p. 64. New York, 1904.

members were apparently connected with rigid web- or jaw-plates it would seem that the pipe fillers on the erection-pins were unnecessary. The preliminary erection of the span in the contractor's yard was an operation very seldom resorted to in America, where it was not considered necessary in first-class bridge-shops. Very complicated connections, those at a difficult angle, and adjacent chord-members were sometimes assembled and fitted together at the bridge-shops, but even this was rare, accuracy being assured by careful inspection, and, in riveted splices, by rimering the field-riveted member to a thick iron template. Admitting that, on account of the location of the bridge, it had been justifiable to erect the trusses at the shops, it would appear much simpler and more economical to have erected them once only, and in a reverse position, that was, with the horizontal top chord supported directly on the surface of the ground. Considerable economy had evidently been attained by the ingenious form of erection-anchorage adopted, but the attendant disadvantage of having to make so many separate adjustments to elevate or depress the semi-arch spans, and the difficulty—practically impossibility—of maintaining the separate cables under uniform stress were serious objections to it as compared with a screw-and-toggle, or hydraulic-jack device. The small number of fatalities and the uselessness of the safety-net were not surprising; many 500-foot spans had been erected in America without any fatalities or serious accidents, and it was his opinion that the height of the structure had very little, if any, influence in causing accidents. Experienced bridge-erectors were never dizzy, and needed rather to be restrained from acts of unnecessary danger and foolhardiness than to be safeguarded against falls. In the United States walking-planks were seldom provided on any falsework or span: the men walked on the track-ties or stringer-flanges, struts, and chords, and practically never fell, although they went fearlessly on long high struts with flanges 5 inches wide, when the wind blew intermittently so hard that they had to lean far over to balance its pressure, and when the structure was covered with snow and ice. Mr. Skinner.

Mr. J. A. L. WADDELL remarked that in discussing this interesting and valuable Paper, there was but little for him to do, except commend; for the design was excellent, the execution of the work masterly, and the appearance of the structure fine. The reader had to exercise his imagination in judging of the last feature, as, unfortunately, no photograph of the finished bridge accompanied the Paper. The criticisms he offered were of a very minor character, and were generally in the nature of a personal opinion. The principal one was that the panels were too short for both economy and Mr. Waddell

Mr. Waddell. appearance. Sixteen panels of 31·25 feet each would have been better than twenty panels of 25 feet each. As far as the floor system was concerned, there was but little difference in the weight of metal per lineal foot of span for the two panel-lengths; because what was lost by the heavier stringers of the long panels was gained by the smaller number of cross girders and connections. There was a little saving of metal in the lateral system on account of the fewer parts, and the economy of truss metal was quite material in the webs; while in the chords the slight increase of weight on account of the greater value of the ratio of unsupported length of strut to least radius of gyration was offset by the less number of splicing and connecting details. The principal economy involved by the use of longer panels, however, lay in the reduction of field-riveting and in the handling of fewer pieces during erection. The appearance of the arch would have been improved by the greater panel-length, because the diagonals near the ends had too small an inclination from the vertical. It would have been necessary to increase the truss-depth at mid-span in order to avoid making the diagonals in that neighbourhood too flat. This could have been accomplished either by raising the gradient 3 or 4 feet or by flattening the arch—preferably the former, if the railroad conditions would permit, as the arch was already flat enough for appearance. American practice would dictate the use of plate-girder spans for the approaches, unless the conditions of transportation were absolutely prohibitory. Even field-spliced plate-girders in these lengths were preferable to open-webbed, riveted girders, provided, of course, that the splicing were properly done. He had shipped by water, without having to resort to field-splicing, heavy plate-girder spans 80 feet long. No special difficulty was experienced in their transportation; but, of course, the freight was higher than that for metal work of smaller dimensions. An improvement in detail would have been effected had a diagonal strut been run in the plane of the upper lateral bracing of each approach-span from each end of the first transverse strut thereof to the top of the end column of the arch, in order to transmit the thrust of the train without causing a horizontal bending on the cross girder of the end bent. This was a detail of construction that for many years has been employed by him in his elevated-railroad designs, and wherever he had attached narrow spans to wider ones, as was done in the bridge under consideration. The use of shallow stringers with intermediate cross girders resting on the top chords was anything but an economic design for the floor-system. It would have been much better to employ deep stringers with cross girders at panel-points only, thus avoiding the necessity of strengthening the

top chords to resist bending. Again, the horizontal struts between the tops of the columns might have been avoided by making the cross girders act as struts. Probably the Author objected to this because of the oblique connections for the ends of the cross girders; but by making the webs deep, as would have to be the case were there no intermediate cross girders, the connection would be simplified. In the vertical sway-bracing the diagonals were evidently proportioned to carry tension only. While this was satisfactory in theory, it was found in practice that long, small shapes in tension could not be relied on to give tight diagonals, and consequently such members failed to check vibration as well as properly designed struts would. Such sway-bracing should not be figured for theoretical stress, but should be proportioned by good judgment for rigidity. The connection for these diagonals at the upper ends was faulty, in that the attachment was to the column only instead of to both the column and the lateral strut. The Author stated on p. 3 that "Mr. J. A. L. Waddell, M. Inst. C.E., calculates the difference in weight of the two types [two-hinged and three-hinged arches] to be 2 per cent." As Mr. Waddell did not remember that he had ever written anything about arches, except what appeared in his work "De Pontibus," it was probable that the Author had made a mistake. The following quotation from that treatise (p. 82) contained all that he remembered to have stated in print concerning the relative weights of arches of various types:— Mr. Waddell.

"Professor Howe finds the relative weights of metal in a 416-foot arch with a 67-foot rise, for cases Nos. 1, 3, and 4, to be as follows:—

Case No. 1, no hinges	1·00
Case No. 3, two hinges	1·21
Case No. 4, three hinges	1·30

The author is of the opinion that, if he were to make three such designs for comparison, there would not be such great differences in the weights, because constructive reasons will cause the designer to use only a few different sectional areas in the chords of an arch; while Professor Howe's students, who, as he states, made the calculations from which the tabulated ratios were determined, probably proportioned the section of each panel length of each chord for the greatest stress to which it could be subjected. This would be eminently proper in making such a comparison; but the results of the computations would not agree with similar results obtained by a bridge specialist."

Using Professor Howe's figures and calling the weight of the two-hinged arch unity, that for the three-hinged arch would be $1 \cdot 3 \div 1 \cdot 21 = 1 \cdot 075$; hence the difference would be 7·5 per cent. instead of 2 per cent. While Mr. Waddell, as was evidenced by the preceding quotation, did not believe that the difference was as high as 7·5 per cent., he hardly thought that it was as low as 2 per cent.—possibly a mean of the two figures, or, say, 5 per cent. would be about right.

Mr. Waddell. An American engineer's criticism of the Plates illustrating the Paper would be that figured dimensions were conspicuous by their absence. Although their insertion might detract somewhat from the neat appearance and artistic finish of the Plates, their great usefulness would far more than offset this minor objection. His experience long ago convinced him that hemp centres for wire ropes were unsatisfactory wherever stretching was objectionable. In fact, he had always made it a practice to avoid the use of hemp centres. Their only advantage was in giving the rope greater pliability, and this was gained by the sacrifice of more important desiderata. The little pins employed for the diagonal connections during the erection of the panels were a clever and useful device, not only because they saved time, but also because they brought immediately all the rivet-holes of the connection at each end of the diagonal into proper position, and thus reduced the amount of drifting to a minimum. In conclusion, he desired to express again his recognition of the care, forethought, and practical engineering knowledge employed throughout the entire design and construction of the Victoria Falls bridge.

Prof. Warren. Professor W. H. WARREN remarked that, as to the suitability of the type of bridge for the site, there could be no question that the braced-spandrel arch possessed a decided advantage in erection over the ordinary arch, where the deck was carried by vertical columns fixed to the extrados of the arch. In regard to the increment of stress due to impact, the Author had adopted a formula similar to those proposed by Mr. J. A. L. Waddell and Mr. C. C. Schneider, but Professor Warren preferred a formula which took into account the inertia of the structure as resisting the dynamical effect of the live loads, rather than one which merely included the length of span, or member under load, neglecting its mass. He considered the formula proposed by Mr. J. W. Schaub to be more satisfactory: it was

$$\mathrm{I} = cl\left(\frac{l}{l + d}\right),$$

where l = live load, d = dead load, c a constant which might have the following values:—0·75 for all train-loads, 0·30 for a rolling load of, say, 20 tons on a roadway, 0·15 for a crowd of people of, say, 100 lbs. per square foot. Where the live-load stress was large compared with the dead-load (e.g. the stringers of a railway bridge), d might be put = 0, and c = 1, I the impact effect would then be 1, or 100 per cent. The bridge appeared to have been very carefully worked out in detail; the method of transmitting the pressure on the pin forming the hinge at the springing to the bearing-pedestal, base-plate, and concrete monolith abutment, was far more satisfac-

tory than any form of steel casting. Again, the arrangement of the four hinges perpendicular to the longitudinal axis of the bridge, and of the bearings of the main rib perpendicular to the resultant thrust, were important features in the design worthy of notice. Another feature affecting the design was the method adopted for transforming the structure at the centre into a three-hinged arch, and then, by means of hydraulic jacks, forcing the ends of the top chords asunder, and imparting to them the stresses calculated for the two-hinged arch, afterwards filling up the gap by suitable packing. This method was, however, not new, and probably the best modern example of its application occurred in the railway-bridge of the Solingen and Ramscheid line over the Wupper valley at Müngsten, an arch of 558 feet span, constructed without hinges. In order to close the arch at the crown in the manner assumed in the calculations, a temporary hinge was inserted in the bottom flange, and the arch was transformed, for the time being, into a three-hinged structure; hydraulic presses inserted at the crown were used to impart the stresses calculated for the arch without hinges. The same method was adopted at the springing to impart the necessary stresses for which the arch was designed. In the Victoria Falls bridge the various joints and connections had been designed in a manner which secured all the well-known advantages of pin-connected bridges, at the same time, however, combining the rigidity and additional security of the riveted connection. This was a detail that would probably be adopted in many future bridges, and the use of the turned pin provided with a temporarily fitted cone at the intersection of the vertical and diagonal members with the centre-line of the arched rib appeared to give all the advantages claimed by the Author. There was, however, the question whether the two-hinged arch in such a case was better than either the rigid or the three-hinged arch. As to the relative merits of the three-hinged, two-hinged, and rigid arch, the dead- and live-load stresses were slightly smaller in the two-hinged than in the three-hinged type, but the temperature-stresses were greater, although considerably less than in the rigid arch. It was clear that the rigid arch was much stiffer and offered a much greater resistance to oscillations than either of the other two types. The maximum deflection recorded at the centre of the rigid arch at Müngsten, when loaded completely with three engines, arranged about the centre with trucks on each side covering the bridge, was only 15·1 millimetres (0·6 inch), whereas the 612-ton test-load at 15 miles per hour on the Victoria Falls bridge of 58 feet less span gave a deflection of 0·84 inch. As to the Prof. Warren.

Prof. Warren. relative stiffness of the two-hinged and three-hinged types, Pr Pearson and Mr. Atcherley had shown,[1] by comparing the types for a span of 108 metres and a rise of 6·5 metres, tl deflections due to live and dead loads, the latter on half the were in the ratio 34 : 25 : 20 for the two-hinged, three-l and rigid arch respectively. The bridge described was a cr all concerned, but it was to be regretted that a more el system of tests had not been carried out, giving the cu deformations for different positions of the live load.

Mr. Williams. Mr. G. B. WILLIAMS considered that more information the Falls would have been welcome, as they were of geological and engineering interest. Possibly the Author throw some light on the question of their geological h Livingstone had imagined that they were caused by a gec convulsion which opened a huge crack across the bed of the and this explanation had been accepted for many years v question. The modern theory was that they had been in the same way as Niagara, by the river cutting its way bacl the gorge below. The engineers in charge of this bridge mu had exceptional opportunities of examining the gorge, any of them were geologists they might have discovered evidence to show whether this process had been the sole caus it had been to some extent assisted by a fault or plane of we in the strata. The geological formations here appeared to l typical of those in many parts of Africa. Over many th square miles in that continent during a comparatively geological period, volcanic action must have taken place scale of which it is almost impossible to form any conceptio had been poured out in successive eruptions, and the laye been piled one on another to a depth of hundreds or even the of feet.

The Author. The AUTHOR in reply, observed that in writing the Paper treated the subject without reserve, his object being to place the engineering world a true account of the undertaking, frankly the reasons for the adoption of all the important me the means employed, the results attained—whether succes otherwise—and the errors committed. He was gratified tl Correspondence, especially that part of it received from engi the Colonies and the United States, expressed the well-con judgment founded upon their great knowledge and experience ;

[1] L. W. Atcherley and K. Pearson, "On the Graphics of Metal Arcl (*Drapers' Company Research Memoir.*) London, 1905.

The Author.

felt that this addition to his communication greatly enhanced its value, especially for reference. The claim advanced by the Author that the two-hinged spandrel-braced arch was the best solution of the problem was not contested—a conclusion which he thought should go far towards the rejection in future of the three-hinged and the braced-rib type of arch for either railway- or roadway-bridges. The ambiguity of stress referred to by Mr. Breithaupt was of course objectionable, but more importance might be attached to the exact calculation of stress than it deserved. The calculated total stresses depended upon numerous assumptions more or less arbitrary, and, being combinations of maximum stresses, were probably never realized in the structure. It would be more correct to design a structure for ordinary stresses with proper impact allowances, etc., and make sure that it had sufficient strength to provide for maximum stresses. This process was to some extent adopted, particularly with regard to wind-stresses, which, when they fell within moderate limits were often treated as extraordinary and were neglected. Reversals of stress were objectionable unless fully provided for. The addition of a comparatively small amount to the cost of a bridge would ensure the provision of ample material in the few members subject to alternating stresses. The chief objection to reversals, at joints where the continuity of the material was more or less broken, applied to pin-joints, and was not applicable to the Victoria Falls bridge, where the joints were riveted and were designed to have a strength corresponding with that of the member, being thus proportionate to the total strength, including impact and allowance for reversals; and there appeared to be no reason why these joints should not be as permanent as the members. The Author agreed with Mr. Buck that the continuity of material, alike in the main trusses and in the lateral bracing of a two-hinged arch, so much increased its rigidity, both vertically and horizontally, as to make it preferable, apart from other considerations, to the three-hinged types. It did not appear that the rigid arch was so superior to the two-hinged arch as Professor Warren stated, from the point of view of rigidity. The latter was simpler to erect, more easily adjusted, and so rigid that it was doubtful whether there was any advantage in making it slightly more so. Several correspondents expressed an opinion in favour of fewer panels, and the Author admitted that an increased panel-length might have been preferable, and that he would certainly adopt the plan in another and better situation. In the present instance he had been influenced by the matter of transport. Increase in the weight of the component parts would have added to the cost of the work, especially of the

The Author. handling at the poorly-equipped port of landing, and of the transportation by cable across the gorge. The weight (10 tons) fixed as the measure of the capacity of the transporter-cable would have been increased had a longer panel-length been adopted. The difficulties, risks of accident, and subsequent delays attendant upon the use of this apparatus had been sufficiently serious with this maximum, and he had now no regret that it had been no higher. Mr. Lindenthal's remarks on the subject of spans greater than that of the bridge under discussion would be useful to designers. A more American arrangement of cross girders and stringers would probably have been preferable to that adopted, which, however, was very simple to erect and reduced riveting to a minimum. Mr. Doak's observations on this point were interesting and valuable. The Author could not deny the force of the argument employed against the trough form of rail-bearer, which form he preferred for reasons of safety. The way-beams in the present case were karri timber, and the rails were not fastened by spikes driven by a hammer, but were secured by bolts and clip-washers, the bolt-holes being bored. He trusted, therefore, that the timbers were not so liable to split as was the experience in Queensland. Mr. Doak's instance of the case of derailment which occurred on the cross ties of a timber trestle without causing serious damage was a bit of experience that was more valuable than much theory; and it added as much in favour of the cross tie as it detracted from the merits of the trough system of floor. The reason why the end spans appeared needlessly long was given in the Paper. If the design of the bridge were raised 21 feet, as it was originally intended to be built, they would not appear too long. Whether they would be better if built as plate-girders was partly a matter of taste. Here again the question of transport had greatly influenced the decision. The design of the arch-bearings had been the subject of much thought on the part of the Author, and he was glad to see that they were generally commended; as pointed out by Mr. Lindenthal, they were essentially different from those at Niagara. The Author was of opinion that they had fulfilled their purpose admirably, and after still further consideration of the subject he was unable to improve the design. He was not acquainted with the design of the bearing referred to by Mr. Skinner. Several correspondents appeared to have failed to understand the method of anchorage adopted. Although no drawings were given, a careful perusal of the description in the Paper would make it clear. The control was not at all complicated, as Mr. Breithaupt seemed to think. The cables could be maintained at uniform stress with perfect ease in the way described in the Paper. If it was necessary

to raise or lower the end of the cantilever it could be done by adjusting one rope at a time, but the ropes were generally operated (after their original adjustment) by the simple device of placing upon, or removing from them, a weight consisting of rails, thus varying their deflection and causing the end of the cantilever to rise or fall. Mr. Skinner's opinion that it was "practically impossible" to maintain the separate cables under uniform stress might be better expressed as "theoretically impossible." The cost of the erection of the Victoria Falls bridge was high as compared with that of the Niagara Falls bridge, but a comparison of the conditions which obtained at the two sites quickly revealed the cause. It was not because the methods adopted in Africa were in any way inferior to or more costly than those pursued in America. The high cost of the erection of the Victoria Falls bridge was due to natural conditions outside the control of the engineers. At Niagara there were advantages in favour of economy in erection, such as cheap, rapid, and easy transport, proximity to sources of skilled labour and to workshops, the absence of which had militated against economy at the Victoria Falls. Mr. Breithaupt's opinion that the extra cost of the latter bridge was justifiable in the circumstances was valuable and was appreciated by the Author. Erection in the shops, objected to by Mr. Skinner, had been justified by the remote position of the site, and the difficulty and delay in supplying any missing part or correcting anything wrong. It had been worth while making certain that all was right and complete before shipment, when a mistake or an omission might have caused a delay of 3 to 6 months. The annoyance and expense of keeping the staff of workmen idle in such a region might be imagined. But it must not be understood that the bridge had been erected complete at one time in the makers' works. The trusses had been erected in the shop once only, in sections convenient for assembling the parts together. So far as the centre portion of the bridge was concerned it had been erected on its back, precisely as recommended by Mr. Skinner. With reference to the remarks of Mr. Doak and Professor Warren, the rule for impact was a purely arbitrary formula. In effect it was very similar to the corresponding formulas that had been largely adopted in America in recent years. Such a method of calculating was simpler than any one involving the use of different unit-stresses, and it ensured the adequate proportioning of the joints—a matter which was liable to be neglected when the working-stresses in the members were varied. An impact-formula which took into account the inertia of a structure as resisting the effect of live loads was certainly the most rational, and Mr. Freeman thought

The Author.

The Author. that the formula adopted practically secured this end, and was moreover easier of application than Mr. Schaub's formula. Both classes of formula necessitated the assumption of a constant (determined by the nature of the load) which was arbitrary, and the effect of the remainder of the formula compared with that of this constant was unimportant. The amount allowed for impact would differ very little whichever formula were used. The stress of 7 tons in compression was a fibre-stress. The corresponding allowable average stress had been calculated by Rankine's formula. Professor Kernot's solicitude regarding "secondary" stresses appeared to the Author to be groundless. The external stresses on the bridge were located exactly by the bearing-pins on which it rested. It was not assumed that the rigidity of the other joints in the structure induced secondary stresses of sufficient magnitude to justify special calculation of them. With regard to the wind-stresses, the assumption that one-half the stresses passed along the upper bracing, and the other half passed down the lower bracing, was fairly justified, the length from a panel-point to the bearings being about the same, measured in either direction, and the systems of bracing being of equal strength. Even with this assumption, the calculation of wind-stresses was unduly laborious in view of the comparative unimportance of such stresses. An exact calculation of them would be a mathematical problem almost impossible of solution in the lifetime of most engineers, and when accomplished it would be of little real value. As regarded tests, it was delightful when engineers could have the structures they designed continually under their observation—as in a laboratory—in order that they might prove the value of their theories and the accuracy of their calculations. But this did not generally happen. In the present instance, extensometer and other measurements, which it had been proposed to take, could not be arranged owing to the difficulties of the situation. In view of the fact that the structure was little exposed to the action of the wind, and that heavy winds were not known in its neighbourhood, the wind-pressure assumed in the calculations was doubtless high, as Mr. Skinner said, but it should not be forgotten that the information available at the time the bridge was designed was meagre in the extreme, and it was therefore only prudent to act well on the safe side. Apart from this, although subsequent experience seemed to indicate that a smaller pressure might have been assumed, the Author would not feel disposed to make any reduction in the strength of the wind-bracing were he to do the work again, alike because the experience of natural conditions in that region was not long enough, and because the members

The Author.

composing the wind-bracing were but light as designed. The diagonals of the vertical sway-bracing referred to by Mr. Waddell were proportioned to carry tension, but in order to secure rigidity and ensure the transmission of half the lateral pressures at chord-joints down the vertical bracing they were made considerably in excess of their calculated strength. The Author would like to commend to young engineers the wise words of Mr. Waddell on the subject of proportioning sway-bracing. The introduction of the small pin appeared to have excited much favourable comment. The Author was surprised that it was not more employed, as it was an excellent device. Regarding the comparative weight of two-hinged and three-hinged arches, the Author was obliged to Mr. Waddell for correcting him, but he did not regret his mistake, since it had educed an opinion from Mr. Waddell which added 3 per cent. to the force of the Author's argument. The elongation of the transporter-cable referred to in the Paper had not been due to temperature, as suggested by Mr. Hunter, since from this cause it could not have exceeded 4 inches. The cable had actually stretched about 8 feet, and the elongation had been due no doubt to the presence of the hemp core. The aggregate weight of permanent-way and bridge material carried by the transporter-cable was about 15,000 tons, exclusive of the weight of the travelling carriage. The latter machine weighed 5 tons. When it was considered that this load of 5 tons was brought to bear on the rope every single journey, whether any other weight was carried or not, it would be seen that the aggregate of such loads soon became very large. If, for example, the conveyor made only forty journeys each way per day for 250 days, the result was 100,000 tons carried by the rope. This was practically what the Zambezi conveyor had done. It had done a great deal of travelling with very light loads—carrying men and stores. The conclusion arrived at by geologists was that the gorge of the River Zambezi was the result of erosive action and was not attributable to earth-convulsion. It was not improbable that the process of erosion had been assisted by planes of weakness in the basaltic rock. The Author could not do better than refer Mr. Williams to the report by Mr. Lamplugh mentioned in the foot-note on p. 2.

26 March, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

(*Paper No. 3650.*)

"The Application of Hydro-Electric Power to Slate-Mining."

By MOSES KELLOW, Assoc. M. Inst. C.E.

THE slate-mines and quarries of Wales are situated, almost without exception, in the mountainous regions of Merionethshire and Carnarvonshire, and their working forms the staple industry of these counties.

The form of the country, in which high hills alternate with deep valleys, greatly facilitates mining and quarrying, inasmuch as it enables the slate beds, which usually incline at relatively high angles, to be approached and worked by adit-levels and horizontal galleries directly from the hillsides, natural ventilation being also available. These advantages of position, by dispensing to a large extent with the necessity for powerful winding-, pumping- and ventilating-machinery, such as is generally required in collieries and metalliferous mines, have caused the amount of power in use to be small, relatively to the magnitude and importance of the undertakings generally.

There is little doubt that it is due to this fact that the mechanical equipment of slate-mines and quarries—particularly in connection with the generation and distribution of power—has not kept pace with the progress made in other industries.

The conditions under which the slate is being worked tend, however, to become less favourable every year, for, as the workings become deeper, natural drainage is no longer possible, winding from the lower galleries becomes necessary, and satisfactory ventilation is more difficult of attainment. Moreover, mechanical aids in the manufacture, as well as in the mining and quarrying, of slate, tend to become more universal every year.

These changing conditions, by involving an increasing use of power,

render the question of the best means of generating and distributing it of considerable importance, especially at the present time, when the stress of foreign competition is so great that the very existence of the industry requires that advantage should be taken of every aid to effective working and cheap production.

By reason of its situation on the west coast, and the high altitude of the mountains comprising the Snowdonian range, which intercept the moisture-laden west and south-west winds, the locality has an exceptionally high rainfall, ranging from 90 inches to as much as 170 inches per annum. The large volume of water which this implies is moreover generally available for storage at a high elevation, so that the two conditions of volume and head, essential to the production of hydraulic power, are present. There is no doubt that, properly developed and applied, there is an abundance of water-power available in the two counties for all the needs of the slate industry.

At present, though in some instances water-power is applied, the bulk of the power for working machinery in the slate mines and quarries is being derived from steam. The disadvantages attendant upon the use of steam-engines, as regards expense and inconvenience, when they are distributed in small units, and especially when situated underground, are so well known to engineers that it is unnecessary to enlarge upon them.

It may therefore be taken that, when the advantages of the economical and convenient source of power in the form of water are more generally appreciated by the mine-owners, and the possibilities of its application to the cheap generation of electricity are fully realized, it will be used almost to the exclusion of any other.

The Author, having designed and installed in North Wales a hydro-electric plant containing features which are in many respects novel, believes that a description of the installation, together with an explanation why the particular forms of apparatus employed were adopted, and some observations upon the application of the principles involved to slate-mining generally, may be of interest.

Hydraulic Installation at the Croesor Quarries.

The property upon which the scheme referred to has been carried out is situated in the Croesor and Cwmfoel valleys, on the slopes of the high mountains of Cnicht and Moelwyn, and in the vicinity of Snowdon. *Fig. 1* is a contoured map of a portion of the property to a scale of 6 inches to the mile. The principal parts of the power-

scheme and the position of the mine are also indicated. *Fig. 2* is a section of the Croesor valley through the power-house.

The property contains within its limits all the essentials of a complete power-system—namely, an ample catchment-area having a

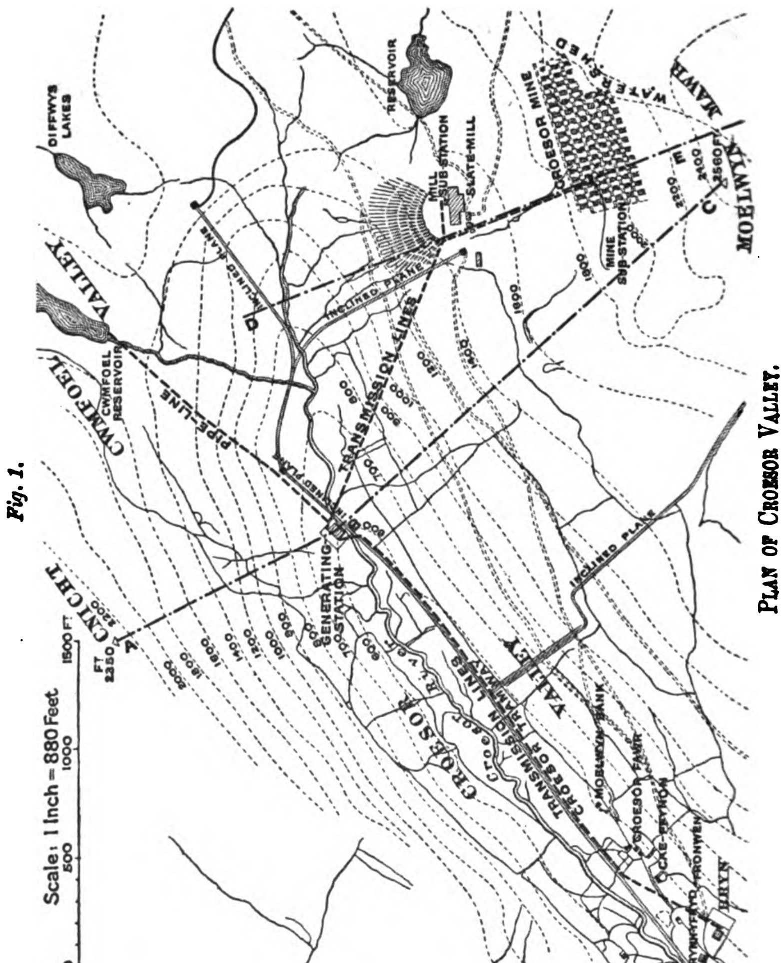


Fig. 1.

PLAN OF CROESOR VALLEY.

high rainfall, large water-storage capacity, and high head of water, enabling considerable power to be obtained—as well as the means of employing profitably the power so obtained in the working of the slate-mines.

Two natural lakes, having an area of about 6 acres, exist at an

elevation of about 1,100 feet above the power-house, and about 1,700 feet above the level of the sea. At present these, with other feeders, discharge their waters into the Cwmfoel valley, which is

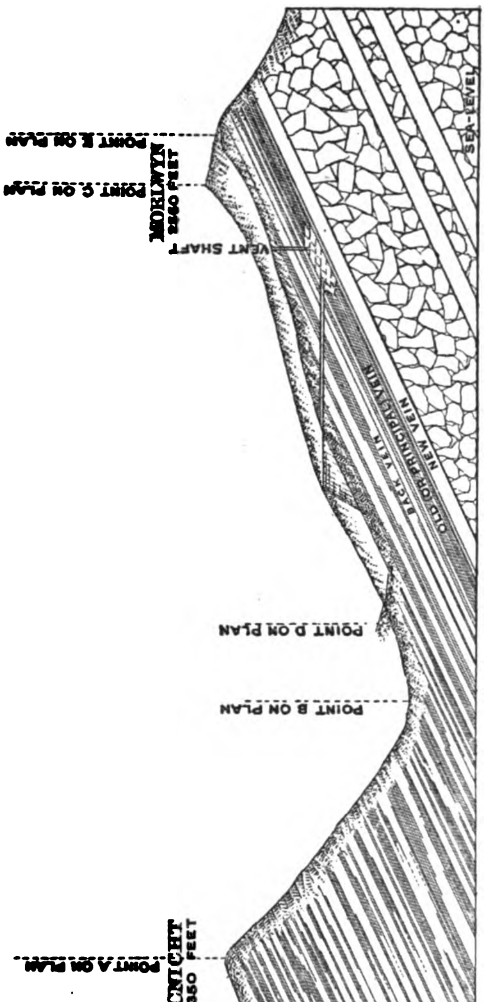


Fig. 2.

SECTION ACROSS CROESOR VALLEY.

enclosed on three sides by high hills. The fourth side, which converges into a narrow opening, has been closed by a masonry dam; and about 12 acres of water have been thereby impounded at an elevation of 860 feet above the power-house, and 1,460 feet above

the level of the sea. So far as the Author is aware, there is no previous example of so high a head of water having been utilized in the United Kingdom.

The higher lakes can, when required, be used to supplement the storage of the reservoir, or can be connected directly to the wheels in the power-house, giving them the benefit of the extra fall. A further reserve is provided by a reservoir on the other side of the Croesor valley. This reservoir is more than 5 acres in extent, is 1,050 feet above the power-house, derives its water from a different catchment-area, and has a pipe-line, 1,200 feet long, already laid.

The form in plan of the dam of the principal reservoir in the Cwmfoel valley was determined by the contour of the ground, and by the facilities for obtaining reliable foundations. Its total length is 263 feet. Of this length, 233 feet is built on solid rock, and the remainder on a bed of impervious clay. The dam is 8 feet wide at the top, and rectangular in section for a depth of 4 feet. Below this there is a batter of 2 feet in 5 feet on the outside. Near the sluices the height is 24 feet, and the width at the bottom is therefore 16 feet. As a provision against leakage, a channel about 5 feet deep was cut, and a guard-wall built in it, in line with the inner face of the dam. The inner face of the dam itself, for a thickness of 2 feet 6 inches, consists of dressed blocks of syenite bedded in Portland cement, the joints being also pointed with the latter material. Syenite was selected for this part of the dam because of its imperviousness to water, and consequent non-liability to disintegration by frost. The remainder of the structure consists of slate rubble masonry bedded in hydraulic lime mortar. As a result of the precautions taken, the reservoir is absolutely water-tight, not a single drop escaping, so far as can be ascertained.

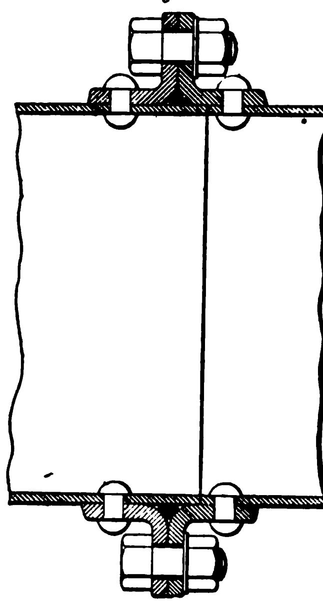
The necessary sluices and three outlet-pipes have been fitted; and to one of the latter a steel pipe-line 3,200 feet long has been connected, extending down to the power-house at the bottom of the Croesor valley; and the water from the reservoir is there applied to driving two impulse-wheels, one of 375 B.HP. and the other of 25 B.HP.

The high pressure of 373 lbs. per square inch necessitated the use of a special form of joint. A recess to retain the packing-material was essential; but the flanges being of wrought steel, and therefore thin, a turned groove in their faces would have weakened them. The plan adopted was to form the pipes with male and female ends, and to utilize the space formed by the curvature of the flanges for the packing material. This avoided weakening the flanges; and, by securing uniformity of section in the pipes, obviated the consider-

able losses due to eddies in the water, which would otherwise have been formed at each joint. A section of the joint is shown in *Fig. 3.* The pipe-losses were further reduced by the use of welded steel, coated with preservative compound, which gave a very smooth interior surface.

The pipe-line has been provided with an air inlet-valve and expansion-joints, and at its lower end, to minimize pressure-variations, with an air-vessel of a capacity of about 30 cubic feet. As the water-pressure was more than 25 atmospheres, it was necessary to provide means for filling it with air at an equivalent pressure. This is accomplished hydraulically by means of a charging-chamber and accessory parts forming the base of the air-vessel. As this is of original design, an explanation of its construction and working may be of interest. The air-chamber is in connection with the pipe-line by a vertical pipe, which passes centrally through a cylinder which forms the base of the apparatus (*Figs. 4*). The annular space between the vertical pipe and the walls of the cylinder forms a charging-chamber. Two cocks and an outlet-valve, controlled by a single lever, enable the charging-chamber to be put into communication with the pipe-line and the air-chamber, or with the atmosphere and the exhaust. When put into communication with the pipe-line, the air contained in it is compressed to a pressure corresponding with that of the water; and, by reason of its lower specific gravity, it rises into the air-chamber above. A movement of the lever closes the passages from and to the pipe-line and air-chamber respectively, and opens the outlet-valve and passage communicating with the atmosphere, thus enabling the water to escape, and a fresh charge of air to be admitted. The outlet-valve is operated through a cam, so as to avoid the necessity for lifting it against the pressure of the water. Gauge-glasses are provided to indicate the height of the water in the air- and

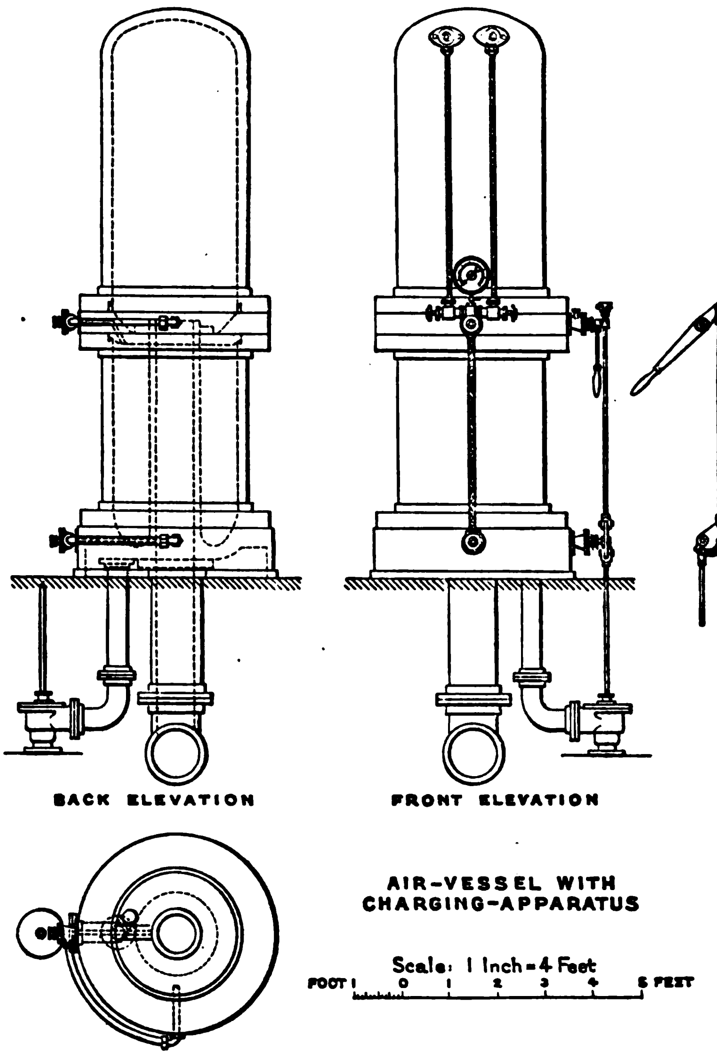
Fig. 3.



PIPE-JOINT.

charging-chambers respectively, and thus to guide the operator in manipulating the lever.

Figs. 4.



Eight relief-valves with knife-edges, giving a minimum of difference between the opening and closing pressures, have also been

fixed at the lower end of the pipe-line, to provide against dangerous rises of pressure.

Some form of impulse-wheel was essential for the high head of 860 feet; but before settling the final form of the buckets, nozzles, etc., the Author carried out a large number of experiments with various forms of each, and under different conditions as regards speed, etc., and having the means at hand for readily and accurately measuring the power developed electrically, a considerable body of data was collected, enabling the following conclusions to be arrived at:—

(1) That the friction of the water against the internal surface of the nozzle retards its velocity, and that the difference of velocities in the centre and at the periphery of the jet introduces a dispersive element, which materially reduces the efficiency of the jet, if its point of application be far removed from the orifice of the nozzle; and that therefore the nozzle should be fixed as near to the buckets of the wheel as possible.

Fig. 5 shows a section of the jet obtained from a nozzle constructed in accordance with Molesworth's formula, and illustrates this dispersive tendency.

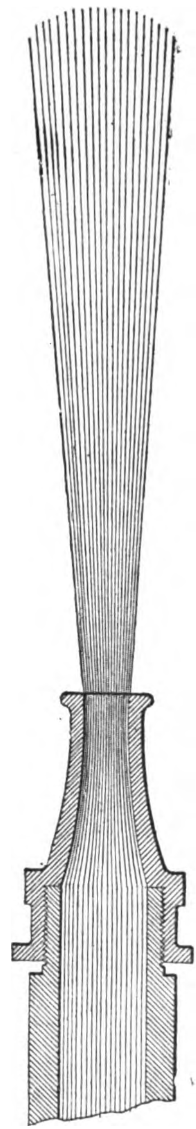


Fig. 5.

JET FROM A NOZZLE DESIGNED ACCORDING TO MOLESWORTH'S FORMULA.

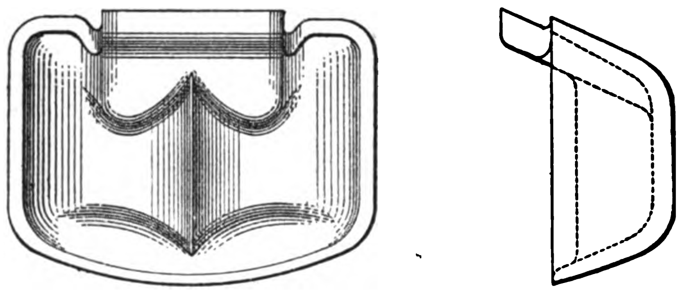
(2) That a pointed spear, or needle, introduced into the centre of the nozzle for the purpose of contracting the orifice has the effect of minimizing the dispersive action, by retarding the velocity of the water in the centre as well as at the periphery, and so making it more uniform; but, as a reduction of the velocity, either at the centre or at the periphery, involves a loss of energy, the efficiency is reduced thereby.

(3) That if such a spear be used, its position in the nozzle must be absolutely central, or the form and efficiency of the jet will be prejudicially affected.

(4) That it is essential to support the spear at a point near nozzle, as any lack of rigidity renders it liable to vibration, wit consequent distortion of the jet and loss of efficiency.

(5) That a bifurcated bucket with a lip, such as the Pelton buck

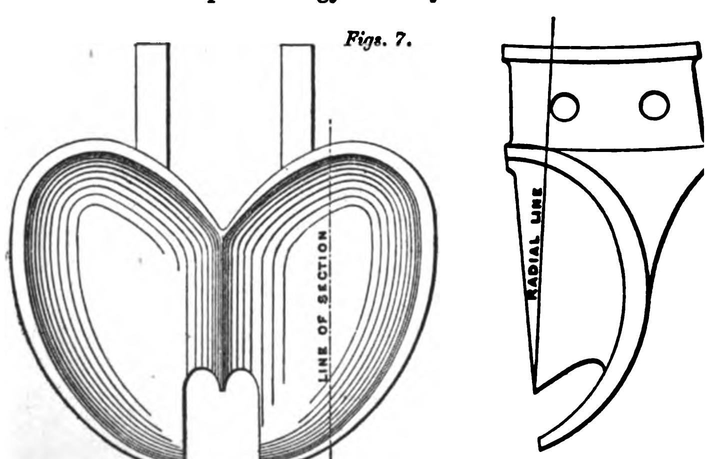
Figs. 6.



"A" Bucket.

does not fulfil the conditions essential to maximum efficiency, as lip and central wedge deflect the jet in two planes, nearly at ri angles to each other, and as the resultant paths cross, the interfere of the streams dissipates energy uselessly.

Figs. 7.



"B" Bucket.

(6) That it is advantageous to omit the portion of the lip whic in the line of the jet; but to avoid the escape of water through opening the path of the water along the bucket must be dire obliquely backwards.

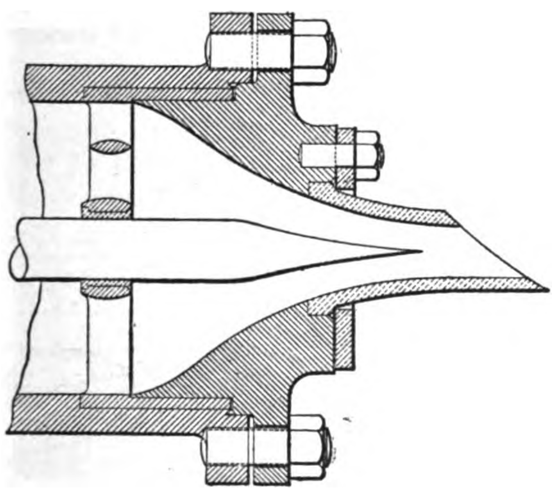
(7) That the peripheral speed of the wheel has an important influence on its efficiency, and that the best results are obtainable at lower peripheral speeds relatively to the spouting velocities of the water than are generally adopted for this type of wheel.

(8) That where a spear is used to control the volume of water passing through the nozzle, there is a wide variation in the best peripheral speeds with different degrees of opening.

For the efficiency-tests, the water was discharged into a tank and accurately measured, the power developed being ascertained electrically for full, three-quarter, half, and quarter volumes of water, and over a range of speeds in each case.

Figs. 6 and *7* show buckets of the two types referred to, and *Fig. 8* shows the form of nozzle and spear adopted.

Fig. 8.



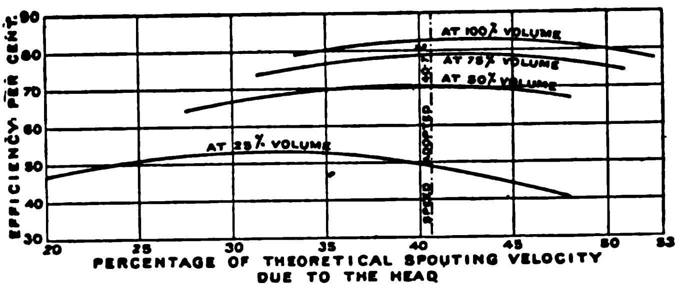
NOZZLE AND SPEAR.

Fig. 9 gives the results of the tests of the wheel when furnished with buckets with closed lips ("A" type) and *Fig. 10* gives corresponding results obtained when buckets with open lips ("B" type) were substituted. The efficiencies are plotted as ordinates; the peripheral speeds as abscissæ. An examination of the curves shows clearly the superiority of the "B" type of bucket, the considerable advantage of working with a fully-open nozzle, and the importance of adopting the best peripheral speed.

The "B" type of bucket was adopted by the Author for each of the two impulse-wheels, with a peripheral speed of 40·7 per cent.

of the theoretical velocity due to the head of water, as indicated b
a pressure-gauge attached to the pipes at a short distance from th
nozzle. This speed was adopted with a view to obtain the highe
efficiency when the plant was working at or near its full load; bu
this does not coincide with maximum efficiencies at smaller loads.

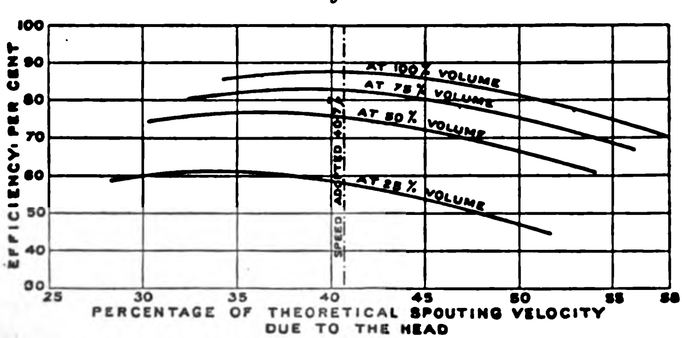
Fig. 9.



EFFICIENCIES OF IMPULSE WHEEL WITH "A" BUCKET (*Figs. 6*).

Fig. 11 shows the wheel-efficiencies at various volumes of water a
a constant peripheral speed of 40·7 per cent. for both "A" an
"B" types of buckets. Pipe-efficiency, combined hydraulic efficienc
and horse-power curves have also been added.

Fig. 10.



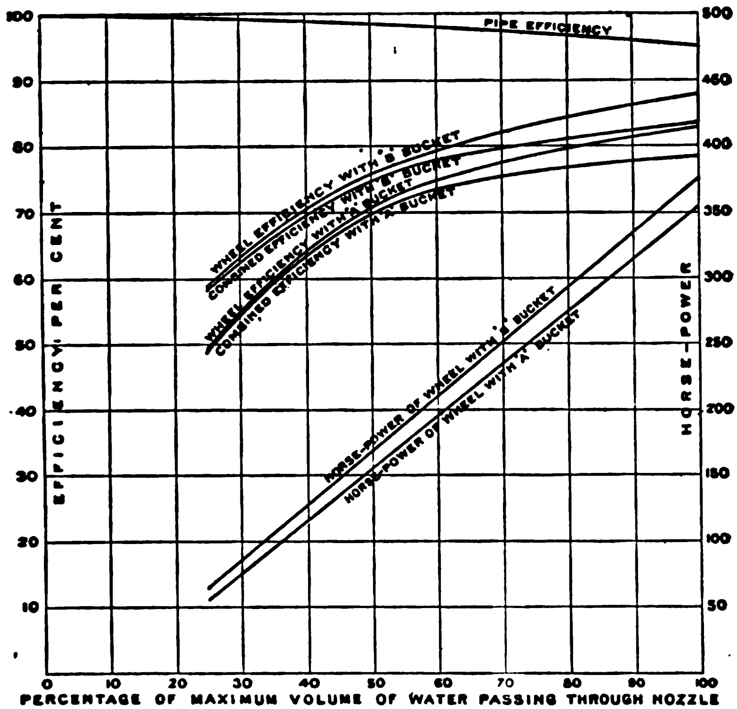
EFFICIENCIES OF IMPULSE WHEEL WITH "B" BUCKET (*Figs. 7*).

In all the diagrams, wheel- and nozzle-efficiencies are take
together.

For both wheels, very sensitive governors, pivoted on knife-edg
and acting through hydraulic relays, control the positions of th
spears in the nozzles; and in the case of the larger one, an o

dashpot is also brought into use, whereby the speed of withdrawal, or insertion of the spear, can be separately controlled and also steadied. Except under severe fluctuations of load, when the relief-valves come momentarily into operation, the variations of pressure in the pipe-line, due to the action of the governors, are kept within

Fig. 11.



EFFICIENCIES AND POWER DEVELOPED BY AN IMPULSE WHEEL.

(Head = 61 feet; volume of water used per minute = 276 cubic feet; peripheral speed (constant) = 40·7 per cent. of theoretical spouting velocity due to head.)

very narrow limits by the air-vessel, and therefore the quantity of water wasted is negligible.

The power-house has been made of sufficient capacity to accommodate three generating-sets, and it is intended to lay additional pipe-lines from the reservoirs when the demand for extra power renders such a course necessary.

The Application of Electricity to Slate-Mining.

As regards the electrical part of the scheme, the Author proposes first to consider the general principles governing the application of electricity to slate-mining, and then briefly to state how these principles were embodied in practice in the plant designed by him.

The electrical systems possible may be broadly divided into (*a*) Continuous Current; (*b*) Alternating Current.

Continuous Current.—With continuous current, a voltage must be adopted which is suited to the generators, the transmission-lines, and the motors, or lamps, as the case may be; and as the requirements of these various elements are not identical, the designer has to adopt what appears to be the best compromise in view of all the conditions of the case. Moreover, the difficulties of commutation in connection with generators and motors place practical limitations upon high voltage.

As, all other conditions being equal, the efficiency of transmission varies as the square of the voltage, high voltage is the very essence of efficient transmission. Therefore when transmission has to take place to any great distance, say 1 mile or upwards, this factor is one of considerable importance, and may become the determining element in the system to be adopted.

For voltages above 1,000, the continuous-current generator is not a suitable machine; so that, where it is desirable to use high tension up to 3,000 volts, or extra-high tension up to say 11,000 volts, to obtain efficient and economical transmission, the use of continuous current becomes practically impossible.

The comparatively high voltages which are generally desirable from the point of view of transmission, are objectionable from the point of view of application; for to have motors and other plant carrying current at a fatally high potential in use by men who generally are not electrical experts, under conditions where there is liability to mechanical injury to insulation, deterioration from wet, and other sources of injury such as prevail in slate-mines, is to incur risk of serious accident to the men, and of damage to the plant.

It is, however, generally assumed that continuous current has advantages over alternating current in the following respects:—

(1) Uniformity of voltage at the point of application, obtainable by over-compounding the generators to balance the ohmic drop in the transmission-lines.

(2) Storage of electrical energy by means of accumulators to equalize the peaks of the load.

(3) Variability of speed, without material sacrifice of efficiency, by varying the excitation of the motors.

(4) High initial torque, and consequent quick acceleration of loads, as applied to winding, haulage, and traction, obtainable by the use of series-wound motors.

(5) Simplicity of the overhead system in connection with traction on tramways, a single conductor overhead only being required.

(6) The positive value of all the current passing, i.e., a power-factor of unity.

In this Paper, however, it is in its applicability to slate-mining, rather than in a general sense, that the subject is being considered. Dealing with these points in the order named above:—

(1) For motors which represent the bulk of the power used, though uniform pressure is a very desirable condition in continuous-current motors, as their speed-regulation depends upon it, comparatively wide variations of pressure do not materially affect the speed of alternating-current motors, as this depends principally upon the periodicity. It is, therefore, in connection with the relatively small lighting element that good pressure-regulation is of consequence in the alternating-current system.

The attainment of this is primarily easier with continuous current than with alternating, by reason of the demagnetizing influence of the lagging currents, which are generally associated with the latter, upon the field system of the alternator, and of the fact that, at least until very recently, compounding and over-compounding had not been successfully applied to alternators. Recent developments, both in alternators themselves and in voltage-regulators, which correct for power-factor as well as for ohmic drop, indicate, however, that the lead which continuous current has in this respect is disappearing.

(2) The extent to which power can be stored electrically is inconsiderable, unless a large outlay is incurred; and, moreover, a very considerable loss is involved in charging and discharging accumulators.

In the slate districts of North Wales, where water is the source of power, it is generally possible to store it, and to generate power as required to meet the varying conditions of load. This, where practicable, is simpler, much cheaper, and more efficient than the storage of energy by means of secondary batteries.

(3) Variable-speed motors would, in any event, be limited to the driving of sawing- and dressing-machinery. It would be desirable in many cases to vary the speed of these machines, to adapt them to different degrees of hardness in the material operated upon; but

a difficulty of application arises from the fact that the machines individually require too small a power to justify a separate motor for each, and with group-driving, the difficulty would be to adjust the speed to suit the several machines constituting the group.

(4) The feature of high initial torque, which characterizes the series-wound motor and gives the power to accelerate loads quickly, is held by many to fulfil the principal requirement of winding and haulage so completely that no other type of motor can hope to compete with it. For winding from a deep vertical shaft, such as an ordinary colliery-shaft, where the attainment of maximum speed in minimum time is the object aimed at, this view is probably correct; but in slate-mines vertical shafts are practically unknown, and haulage on inclined planes, following the dip of the slate-beds, is the usual condition encountered.

Very high speeds are not advantageous; about 750 feet per minute marks the practical limit. At this, and lower speeds, the power required to accelerate the load is not very considerable; and though the high initial torque, which is characteristic of this type of motor, is advantageous so far as it meets the requirements of acceleration, it is generally so much in excess of these requirements that it has to be considerably reduced rheostatically, in order to start the loads without throwing them off the rails.

The conditions that suit the peculiarities of the series-wound motor are also that heavy loads are wound at a low speed, and light loads at a high speed. If these conditions are not fulfilled, rheostatic control again becomes essential. In slate-mines it is the character of the load and not its weight which limits the speed at which it can be drawn up. Blocks of slate intended for the dressing-mills, and constituting a fair proportion of the total traffic, are frequently of awkward shapes and difficult to balance on the trollies. With the displacement of the centre of gravity due to the trollies coming on to an incline, this difficulty becomes accentuated.

As therefore, both at starting and in the subsequent winding, the successful operation of the motor depends upon the entire current (armature and field) working it being controlled rheostatically, the efficiency is necessarily considerably reduced; and the Author, while recognizing the advantages of this type of motor for winding-gears generally, does not by any means regard it as a *sine quâ non* under the particular conditions which exist in slate-mines. On the other hand, for traction along the tramways, on the galleries, and in the levels of slate-mines, series-wound continuous-current motors, arranged so that they can be run alternatively in series or in parallel, are superior to any other type, as is proved by their almost

universal adoption in street-tramway work, where the conditions are similar.

(5) A single overhead conductor, with rail return, affords the maximum of simplicity combined with economy in the transmission of power to the motors of a locomotive.

(6) The advantage of a power-factor of unity, and therefore no disparity between apparent and real watts, and the effect of this on the general efficiency of the system, is undoubtedly an important point to be taken account of; but it is only one factor out of many, and exaggerated importance must not be attached to it.

Alternating Current.—In comparison with continuous current, a point which stands out conspicuously is, that the voltages of generation, transmission, and distribution can each be determined independently of the other, and therefore that best suited to the circumstances can be adopted in each case. This is rendered possible by the use of the static transformer, which can be used to step up, or step down, the voltage as required, either at the generating or at the distributing end of the transmission-line.

Between single-phase and polyphase systems, as applied to slate-mining, the predominance of the motor element as compared with the lighting, practically determines the question in favour of the latter. Polyphase motors are superior to single-phase in every point upon which a comparison can be made—cost, starting-torque, efficiency, power-factor, overload-capacity, and weight in relation to power. On the other hand, the current required for lighting, being taken from a single phase, or between phases, necessitates some care in arranging the circuits, so as to distribute the load equally between the various phases, and avoid throwing the system out of balance, if a polyphase system be adopted.

Polyphase systems are practically restricted to two-phase and three-phase. Two-phase has the advantage, when it replaces continuous current or single-phase alternating current, of enabling existing conductors which have been laid in pairs, to be utilized, and is for this reason frequently adopted for converted systems; but for an entirely new plant it has no advantage which is not possessed by three-phase, and is in some important respects inferior to it.

The advantage obtained by the three-phase relation as regards transmission is a factor of prime importance. The algebraic sum of the currents in the three-phases being always zero, the ends of the various phase-windings in the generators and motors may be connected together; a single conductor thus sufficing for each phase and no returns being necessary. For the three-phase system, star connected, the transmission-losses are only one-fourth as great as in

a continuous-current system; the basis of comparison being the virtual voltage between line and neutral in the case of three-phase, and the voltage between lead and return in the case of continuous current, the weight of copper being the same in both cases. In view, therefore, of the superiority of the three-phase system, the Author will confine his remarks chiefly to it.

The choice of periodicities in connection with slate-mining is practically confined to 25, 40, and 50 cycles. The principal considerations affecting this choice are the following:—

(1) For a given number of poles in the stators of the motors, the speed varies directly as the periodicity, therefore a low periodicity is suited to low-speed motors, which are most commonly required in slate-mining.

(2) The characteristics of motors in general, and their power-factor in particular, are better at low than at high periodicities.

(3) A low periodicity facilitates the parallel running of generators (where required) and a smaller fly-wheel effect is necessary than at higher periodicities, as the permissible value of the cyclic irregularity of the prime movers is greater. This is chiefly applicable to cases where the generators are engine-driven, as the cyclic irregularity with turbine driving is almost negligible.

(4) A low periodicity is essential to the working of rotary converters. At 25 cycles the performance of these machines is quite satisfactory, at 40 cycles it is practicable, but above 40 cycles the use of a motor-generator, which is less efficient, becomes a necessity. Generally speaking, however, this is not of much importance, as it only affects the question so far as it may be necessary to transform three-phase to continuous current; moreover the adoption of rotary converters frequently necessitates the use of special transformers, to obtain the correct ratio between the voltages on the alternating- and continuous-current sides of the machines.

(5) High periodicities give a correspondingly larger range of available speeds for motors than lower ones.

(6) High periodicities are more favourable for lighting than lower ones. Arc-lighting is impossible, and incandescent lighting is indifferent, at 25 cycles; but both are available and fairly satisfactory at 40 or 50 cycles.

(7) Static transformers are considerably less bulky and expensive at high than at low periodicities.

In the Author's opinion the periodicity best suited to slate-mining is 40 cycles, but 50 cycles is only slightly inferior, and the standardization of the latter figure will probably render its adoption advisable in the majority of cases.

The revolving-armature and inductor types of alternator are now practically obsolete, the latest practice involving the use of the stationary-armature revolving-field type. The enormous advantage of taking the current from the stationary element in the machine, instead of the rotating element requiring the use of collecting devices, the other good electrical characteristics, and the excellent mechanical construction possible, have been, no doubt, the principal factors in popularizing this type.

As there is not the least difficulty in building generators of this kind for voltages up to 11,000 volts (this being now standard), which is ample for efficient transmission to any distance within the slate-districts, only step-down transformers are required in any case; but in the event of its being possible to generate electricity, say within ½ or ¾ mile of the point of application, it will be better to dispense with transformers altogether, and to generate at the distribution voltage.

Whether the source of power be water or steam, direct driving should be adopted, if at all possible. Where a steam-engine supplies the motive power, the generator, when directly driven, is necessarily of low speed, and therefore a bulky and expensive machine in proportion to its output, the speed being limited by what the engine is capable of running at. With water-turbine driving, however, the only limit to the speed of the generator is that imposed by the ultimate mechanical strength of the rotating-field system; and this being high, a very compact, cheap, and efficient machine is possible. The performance of such a machine is, in fact, superior to that of a larger and more expensive one, by reason of the better fly-wheel effect obtained at the higher speed.

Mounting the exciter upon the alternator-shaft has the merit of making a neat and compact combination, but it has the disadvantage of accentuating the effect upon the voltage of variations of speed; for an increase or decrease of speed involves not only the direct rise or fall of voltage corresponding with it, but also that due to the variations in the voltage of the exciter reacting on the alternator-field. On the whole, therefore, especially where lighting is an element, it is better to drive the exciter separately.

Above all things, mining-plant, including electrical, must possess, to the fullest possible extent, the qualities of reliability, first-class mechanical construction, and simplicity of operation.

As regards motors, in the Author's opinion these conditions are fulfilled by the three-phase induction type to a greater extent than by any other.

As compared with continuous-current motors, the application of

the current to the stationary, instead of the rotating element, and the consequent elimination of commutators and brushes with their attendant troubles and maintenance, is a point in their favour of very considerable importance.

While induction motors may be broadly divided into two classes—those with wound rotors and those with short-circuited rotors—the further subdivision of which these classes are capable, renders available many varieties of motor, each possessing characteristics which render it suitable, or otherwise, for the varying service required in slate-mining, so that some care has to be exercised in the selection of the right type in each case. The consideration of these will therefore be taken in connection with the nature of the work they have to perform.

Without re-designing the whole of the existing sawing- and dressing-machinery, the units are too small, and their speed is too low, to render separate driving of each machine advisable. On the other hand, where, as in some cases, as many as one hundred machines are contained in a mill, driving by a single large motor, and transmitting the power by long lines of heavy shafting, is equally inadvisable.

In addition to the question of efficiency of driving the machinery, and really of much greater importance, are the questions of economy of men's time and facility of operation. From many causes temporary stoppages of the machinery become necessary, and while the necessity for such a stoppage may arise from a single machine, a stoppage of the whole mill is involved if it is driven by a single large motor. Moreover, the stopping and starting are beyond local control. The best arrangement therefore appears to be the driving of groups, consisting of eight to twelve machines, by separate motors, locally controlled.

Undoubtedly the most mechanical, reliable, and simple type of motor is the one with a squirrel-cage rotor. When constructed for the highest efficiency and power-factor, it is, however, lacking in starting-torque, and takes a heavy starting-current, unless an external device, such as a resistance or an auto-transformer, is used to reduce it, which again further reduces the already low starting-torque. If, however, group-driving be adopted and comparatively small motors be used, it is possible to arrive at a satisfactory compromise by slightly sacrificing efficiency and power-factor, and thus obtain the requisite starting-torque, as also sufficient reduction in starting-current to render the motor independent of any starting-device, beyond a simple switch which can be operated by any inexperienced person.

While this is the simplest and most reliable arrangement, a very

good alternative is a motor with wound rotor, and internal starting-resistance, which cuts out automatically as the machine runs up to speed. This is easy to work, and high power-factor, efficiency, and starting-torque are obtainable; but in mechanical strength and simplicity, as well as in first cost, it is inferior to the squirrel-cage type.

For winding up inclined planes, where relatively large motors are employed, and frequent starting, stopping, and speed-control are necessary, it is essential to use wound rotors in conjunction with controllers and outside resistances.

The use of wound rotors (in conjunction with the auxiliary devices referred to) enables the motors to be controlled through their secondary elements, which has the advantage, over control through the primary element, of involving no sacrifice of power-factor, and of rendering available the maximum torque the machine is capable of exerting for starting, and also over the whole range of speeds.

In considering the suitability of a three-phase induction motor for winding, the conditions almost universally prevailing in slate-mines must be borne in mind :—

(*a*) The trucks are being drawn up inclined planes.

(*b*) Several trucks are generally being drawn up simultaneously, and on different roads.

(*c*) The traffic is a mixed one, consisting of rubbish and blocks of slate for the mills.

(*d*) Different speeds of winding are not possible for the two classes of traffic without complicating the winding-arrangements, and therefore a speed suitable to both must be adopted.

(*e*) The speed of winding is fixed by the character and not by the weight of the load or loads to be lifted.

(*f*) Whether one load is being lifted or two or more loads simultaneously, the speed should remain the same.

As the variation of speed with load of a large three-phase induction motor will not exceed 3 to 4 per cent., within its normal working-range, the conditions as to speed required for winding are admirably fulfilled, without involving any rheostatic losses, such as would be involved in similar speed-regulation of a series-wound continuous-current motor.

In all other respects, such as starting-torque, rapid acceleration of load and speed-control, a three-phase motor may be made to fulfil all practical requirements.

The efficiency of the rotor being inversely proportional to slip, that of the whole machine is certainly low, while its speed is materially below the normal; but as in a properly-designed plant,

the time during which the motor will be running below its normal speed will be but a small portion of the total, the overall efficiency will compare very favourably with, and probably be superior to, that of any other type of motor it is possible to instal.

For driving reciprocating-pumps it is certainly necessary to use a type of motor which admits of using resistance in the rotor-circuit, in order to obtain the requisite initial torque for starting and accelerating the column of water; but for pumps of the centrifugal type, the multi-stage variety of which, directly coupled, is admirably suited for slate-mining, the short-circuited, or squirrel-cage type, may be used, the starting-current being kept down by an auto-transformer. The difference is that in the latter case no movement takes place in the column of water until the motor is nearly up to speed, and hence the motor practically starts light.

For driving fans, winches, etc., the most suitable type will depend upon the size, starting-torque required, frequency of operation, and cost of current, and will be governed by the same principles as the particular cases already considered.

The methods of starting, either by simple switch, auto-transformer or resistance in the rotor-circuit, or otherwise, for all motors throughout the system, will also be influenced by the importance or otherwise of a high power-factor, and of uniformity of power-factor. The first two methods are inferior to the third in these respects, but render possible a more desirable type of motor.

A low power-factor is disadvantageous, as it involves the partial loading of the plant with wattless current; but as the total losses due to this in any well-designed three-phase system, as regards the generating, transmitting, and transforming apparatus, will not usually exceed 2 per cent., the losses due to the method of starting, being only a small fraction of this, will not be of great importance.

A variable power-factor is disadvantageous, as it renders good voltage-regulation difficult. The lag or lead of the armature-current has a far greater effect on the voltage of the generator than that due to ohmic resistance; and as the power-factor of the current taken at starting by induction motors (when a resistance in the rotor circuit is not used) is usually 0·15 to 0·3, as against, say, 0·85 for ordinary loads, an element of variability is introduced which is not easy to correct. This, however, only affects the question to any practical extent as regards lighting, and a high standard in this respect is not so essential for mines as for town lighting.

Summary of Advantages of Three-Phase System.—The advantages of three-phase current, as applied to slate-mining, may be summarized as follows:—

1. The voltages of generation, transmission, and distribution can be separately determined, so as to give the best results obtainable in each case.

2. Higher efficiency of transmission than with any other system.

3. Higher efficiency of the generators, when turbine-driven at high speed.

4. Substantial mechanical construction in generators and motors and consequent immunity from breakdown.

5. Collection of current from, and its application to, the stationary element in generators and motors respectively.

6. Absence of commutators and brushes, which are the most delicate and troublesome elements in continuous-current machines.

7. Simplicity of operation, especially where the power is distributed in small units by squirrel-cage motors.

8. Suitability of motors for the various classes of work requiring to be performed (including winding).

The foregoing are, in the Author's opinion, of such weight when taken collectively that the superiority of the three-phase over any other system is clearly established.

Where long-distance transmission is an element in the question, material advantages are obtained; but the superiority of the three-phase system is not limited to this condition, its reliability and simplicity rendering its adoption preferable for slate-mining work under all conditions.

The Author intends these remarks to apply to the system generally, and does not exclude the use of continuous current for such a special purpose as traction.

In accordance with the conclusions enunciated above, the Author adopted the three-phase system in his power-scheme; and as it is the first, and at the date of this Paper was the only three-phase plant installed and working in a slate-mine in the United Kingdom, a brief description of it may prove of interest.

Electrical Installation at the Croesor Quarries.

The 375-HP. impulse-wheel, referred to earlier in this Paper, is direct-coupled to a 250-kilowatt three-phase alternator; and the smaller impulse-wheel is applied to driving two small continuous-current generators, also directly coupled. The alternator runs at 600 revolutions per minute, and is of the revolving-field, stationary-armature type. Mounted on a single bed-plate of cast-iron, the wheel and alternator make a very compact and effective combination. Similar remarks apply to the smaller set.

Either of the continuous-current generators may be used for excitation, the one not in use for the purpose being employed to light and heat the Author's house, which is about 1 mile distant.

Both alternator- and exciter-sets have heavy steel fly-wheels mounted on their shafts, with the object of securing good speed-regulation.

The alternator is wound for 2,750 volts between phases, and, being star-connected, this corresponds to 1,587 volts per phase. The adoption of 2,750 volts as the voltage between the phases was influenced partly by the desire to keep within the limits of high tension as defined by the Government Regulations. The voltage is automatically regulated by means of a Thury regulator.

The periodicity of the system is 40 cycles per second, the lower speed of the motors thus obtained, as compared with that of 50 cycles, enabling single reduction-gear to be used, instead of double, for the major part of the applications required, the results being gains in efficiency, compactness, and cost.

The transmission-line consists of overhead wires for a distance of 3,200 feet, at which point it branches, one part being continued as an overhead line to the mills, and the other part, consisting of a three-core cable 1,500 feet long, going underground.

At the respective ends of the lines, in the mills and underground, oil-cooled three-phase transformers reduce the voltage to 220 volts between phases for local distribution.

The mill-machinery has been divided into groups consisting generally of eight machines, but in some cases more, each group being driven by a separate 10-HP. motor. These motors are of the squirrel-cage type, designed for an initial torque 1½ times the normal. They are started against load by a simple switch, and it is interesting to note that, notwithstanding the comparatively large size of the motors, not the slightest objectionable feature has ever manifested itself as a result of this method of starting.

The mills are also lighted electrically by two hundred and forty 32-candle-power glow-lamps, connected between the phases.

Underground, a 90-HP. motor, combined with a reversing controller and resistance, is used for winding on an incline. It is capable of dealing with a load of 5 tons, and for a single gallery the complete operation occupies about 20 seconds.

A two-stage centrifugal pump, directly driven by a 35-HP. motor, deals effectively with the mine-water.

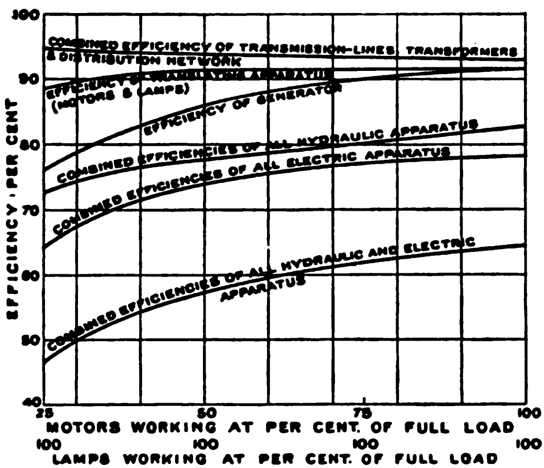
A motor-generator produces continuous current for working an electric locomotive, which is, the Author believes, the first one electrically driven applied to mining in this country. It has two

series-wound continuous-current motors of 15 HP. each, arranged to work in series or in parallel, and give normally speeds of 4 miles and 8 miles per hour respectively, when hauling a train of 30 tons. Other speeds are available by rheostatic control. In facility of working this locomotive leaves nothing to be desired.

Electrically-driven winches have partially replaced the old hand-operated tripod cranes, and have proved eminently satisfactory.

The main underground level, shunting-siding, main incline, and the approaches thereto, have been lighted by glow-lamps, and arc-lighting, applied experimentally to one of the underground

Fig. 12.



EFFICIENCIES OF HYDRO-ELECTRIC PLANT.

chambers, has given such satisfactory results that its extension to other chambers is contemplated.

Fig. 12 shows graphically the various efficiencies of the system, from which it appears that when the motors are working fully loaded, it is possible to obtain at the mine, in the form of mechanical energy at the motor-shafts (or its equivalent at the lamp-terminals) 64·43 per cent. of the potential energy of the water in the reservoir 1½ to 2 miles distant; and that even at half-load on the motors (a very exceptional condition) the figure is still high, being 61·75 per cent.

The whole plant has been in operation upwards of 2 years; no

hitch of any kind has occurred, and the working has been completely successful.

The Author craves indulgence for the introduction of certain matter which is common knowledge to electrical experts, but this Paper has been written for the purpose of considering the question from the point of view of the mining and quarrying, rather than that of the electrical expert; and moreover the statement of some elementary facts has been essential to the full exposition of the Author's views.

The Paper is accompanied by eight drawings from which the Figures in the text have been prepared.

(*Paper No. 3698.*)

"Electrically-driven Winding-Gear, and the Supply of Power to Mines."

By Arthur Henry Preece, M. Inst. C.E.

The use of electricity in mines has become so general that it is unnecessary to dwell upon its advantages for ordinary purposes. Special regulations for its use have been issued by the Home Office, and all candidates for the position of Inspector of Mines have to qualify in electricity as one of the subjects of examination.

The operating of main winding-gears by electricity is little practised in England; a few small winders have been put in, and one large one of about 1,500 HP. is now being erected in South Wales. On the Continent, probably because coal is dearer, and also because more development work is going on, especially in Germany, winding by electricity is progressing very rapidly. In fact, one firm alone have in hand about forty large winders, some dealing with 2,000 tons of coal per day and lifting from depths of 900 yards.

The principal coal-mining districts in Great Britain are being placed within reach of a cheap supply of electricity for power, and many colliery-owners who have not adopted electricity for power purposes will no doubt be induced to consider the subject more thoroughly. One of the important points for consideration will be the cost of electricity purchased from an outside source as compared with the cost when produced by an installation at the mine; and in the second portion of this Paper the Author proposes to discuss some aspects of this question.

I.—ELECTRICALLY-DRIVEN WINDING-GEARS.

In competing as a medium for driving winding-gears, electricity is faced with a very strong adversary in steam-engines, which have been used for winding for many years, and are simple and reliable. They are not expensive in first cost, and the annual expenditure upon their upkeep is low. In some cases, engines which have been installed in mines for 30 to 40 years are now in daily use, and appear as good as when they were first installed. There is little doubt, however, that even the most modern steam winding-engine is not highly economical of steam.

Electricity can be manipulated with greater facility than steam, and it is far more flexible. The turning moment of an electric motor is of an even character, and when starting a motor proceeds at constant acceleration and no undue strains need be produced upon the rope. Steam-engines when used for deep shafts necessitate enormous weights in moving parts, causing difficulties in balancing and difficulties with ropes. The use of electricity would enable two-stage lifts to be used; and even without the use of two stages, winding from great depths could be satisfactorily accomplished with electricity owing to the better starting-torque and the reduction in the weight of moving parts.

One of the chief difficulties with winding in deep shafts is the question of the rope, and this difficulty is considerably increased by the use of reciprocating steam-engines. The work performed by such engines is necessarily of a jerky character when starting under load: at the moment of starting, only one cylinder is at work, and it is not until the two cylinders are in full action that it is possible to get any benefit from the fly-wheel effect of the moving masses. The result, especially in deep mining, is much swaying and jerking of the ropes, and where tail-ropes are used, the probable effect is considered by many mining-engineers to be quite sufficient to condemn their use.

It has been shown experimentally that an electric locomotive will pull a greater weight per ton of adhesion weight at starting than a steam locomotive. In one case every ton of adhesive weight of an electric locomotive pulled 12½ tons without slipping, whereas for every ton of a steam locomotive only 8½ tons could be pulled. This may be assumed to be entirely due to the irregular action of a steam-engine in starting.

Another point to be considered as a disadvantage with steam-engines is the friction-loss at starting. Mr. H. C. Behr, M. Inst. C.E., in the able Paper which he contributed to the Institution of Mining and

Metallurgy[1] in 1902, has assumed that this reached as much as 20 per cent., though this figure was in a measure refuted by speakers in the discussion on the Paper. It is clear that in dealing with large steam-driven winding-plants the starting-friction is enormous, and as the machinery has to be stopped and started fifty to seventy times per hour the resultant loss through friction is very considerable.

In the case of electric winding the motor practically forms part of the winding-drum, and the friction and electrical losses are comparatively small.

A valuable Paper, on the cost of electric winding as applied to coal-mining, was recently discussed by the Institution of Electrical Engineers.[2] No details were given regarding the engineering aspect of electric winding itself, but numerous interesting calculations were brought forward regarding the difference in the cost of working between steam winding and electric winding. In the opinion of the Author, it appears almost impossible to arrive at any fair comparison with existing steam or electric coal-winding plants; for not only does the quantity of coal to be raised vary considerably in every colliery, but the depth is different, and the working-conditions and cost of coal are not comparable.

Tests of electric winders have been made in Germany, and figures will be given later referring to this matter, but comparison with what has been done on the Continent is not necessarily a fair basis, because the working-conditions are so essentially different. One interesting feature is that on the Continent time appears to be of less importance, with the result that decking-operations take two to three times as long as they do in England. This considerably alters the curve for the power-demand, and affects the general question of efficiency.

In adopting electricity for winding in mines, it is by no means essential that the electrical designer should follow the practice that has been adopted—no doubt after many years of experience and careful experiment—with steam-winding. Methods of winding which have proved successful for steam are not necessarily the best for use with electricity. An electric motor coupled direct to a winder has the advantage of getting rid of the difficulty of balancing, which is so much experienced with steam-engines. Possibly the use of the Whiting, Koepe or other form of sheave-drive will be more largely adopted with electricity.

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[1] "Winding-Plants for great depths." Transactions of the Institution of Mining and Metallurgy, vol. xi, Part 1.

[2] W. C. Mountain, "Electric Winding in Main Shafts considered practically and commercially." Journal of the Institution of Electrical Engineers, vol. 36 (1906), p. 499.

Mechanical Questions in Winding.

The advisability of considering all the mechanical questions arising in winding-problems has, perhaps, been more generally recognized in the last few years; and the Paper by Mr. Behr, to which reference has already been made, and the complete discussion which followed it at home and in South Africa, may be said to have been the most important recent contribution to practical knowledge of the subject. In 1905 Professor P. Habets, of Brussels, read a Paper at the Institution of Mechanical Engineers[1] principally on electric winding and certain tests which he had carried out. These Papers are worthy of thorough study by anyone who has to deal with this matter.

It must not be assumed that winding by electricity can be considered entirely analogous to electric traction. A very little consideration of the question will show that there are numerous additional factors which have to be dealt with. With traction experience has indicated a definite allowance for obtaining the tractive effort and for friction on curves, the gravity component on gradients is easily obtained, and the forces required for acceleration and retardation are merely limited by questions of economy and public convenience.

In winding it is essential to study the inertia of the suspended loads, the static and dynamic stresses on the ropes, the momentum of the winding-gears, the varying weights, the questions of balanced and unbalanced loads, the friction of the shaft, the acceleration, and the retardation. In the case of steam-engines it is further essential to consider the friction of the moving parts, and the difficulties of starting at full load with the crank and valve-gear at inconvenient positions.

Even assuming that the load to be lifted, the time of each journey, and the period for unloading are definitely fixed, there are numerous combinations possible which would require careful consideration, such as, whether cylindrical or conical drums, or sheave methods of winding, such as the Whiting, Koepe, or other method, should be used, whether ropes are to be balanced or unbalanced, and whether tail-ropes are permissible.

In the case of very deep mines, up to 6,000 feet, it has to be considered whether two-stage winding would be better than single-stage.

There is also the question of the different maximum speed when

[1] "Electric Winding-Machines." Transactions of the Institution of Mechanical Engineers, 1905, p. 429.

lifting materials and when lifting men. This may be solved by providing separate winding-gear; but it is obvious that men cannot be lifted or lowered at the same speed as a load of materials, and if one winding-gear is to be used for both, it must be capable of working economically at a low as well as a high speed.

The following Table, obtained from Mr. Behr's Paper, will give an idea of the variation in the starting-moment and inertia due to acceleration with balanced and unbalanced ropes and taper ropes:—

Type.	Depth.	Weight of Load.	Weight of Rope.	Starting-Moment.	Inertia of Acceleration.	Time of Trip.	Maximum Velocity.	Factor of Safety.	HP. at Maximum Speed.
	Yards.	Lbs.	Lbs.	Lb.-ft.		Sec.	Ft. per Sec.		HP.
Cylindrical drum, unbalanced parallel rope, drum 12 feet in diam.	1,000	8,100	9,000	165,000	86,655	92·25	36	7	1,527
Ditto, but with taper rope . .	1,000	8,100	7,160	152,780	82,515	91·3	36	7	1,382
Ditto, but with balanced rope .	1,000	8,100	9,000	98,780	96,780	91·3	36	7	886

The methods of calculation and the diagrams furnished by Mr. Behr's Paper give a thorough idea of the working out of the final details of any particular winding-gear, but it appears to the Author that, when considering electric winding for preliminary purposes, a simpler method of approaching the subject is to work on the basis of the greatest pull allowable with the rope.

It must be recollected that the moment available for acceleration with an electric motor is only limited by the overload capacity of that motor. Hence, if the useful load to be taken by the motor is determined, it is only necessary to design a motor to take an overload sufficient to give the acceleration to the total moving masses necessary to get up to the full speed. The overload is determined by the time during which acceleration is required; by the period at full load; and by the period at no load when the motor is able to cool.

It may be assumed that the maximum pull on the rope should not exceed double the weight to be lifted. This may be true for mines not exceeding 3,000 to 4,000 feet in depth, but in deeper mines the maximum torque could not be so great. The pull on the rope at starting is equal to $L + I \times \frac{a}{r^2}$; where L is the load, I is the combined moment of inertia of all the moving masses, r is the radius

of the drum, and a is the acceleration. Hence $I \times \frac{a}{r^2}$ should not exceed L, the load. From this it should not be difficult to determine what the maximum acceleration should be. I is determined from the inertia of the drum-sheaves and of the rope, cages, and weight to be lifted, bearing in mind that in the case of a balanced rope three times the weight of the rope must be taken.

The capacity of winding-gears when driven by steam-engines is governed largely by the limitations necessary in the design of a steam-engine, but in the case of electric motors no such limitation occurs. Provided the rope can be made to withstand the stresses, and provided means are available for concentrating a supply of cheap electric energy at the mouth of the shaft, there are no limits to the design of an economical electric motor to do the maximum work required in the shaft.

Winding from Deep Shafts.

One of the most important of the coming problems in mining is the necessity for winding from deep shafts. Two-stage winding is open to many objections, even if a cheap and convenient method of power-transmission, such as the use of electricity, were adopted; but it is obvious that the installation of an electrically-driven winder half-way down a shaft is a much simpler matter than the installation of a steam-driven plant, or than transmission by means of ropes to a separate winder at the lower level from a steam-driven winder on the surface. It appears to the Author, however, that if by the use of electrical winding deep-level mines can be worked single-stage, a great gain would be obtained by the mining-industry. A single-stage winding is largely a question of rope-strength, and the crucial point is the factor of safety to be adopted. It is possible that electric winding, with its steady action and consequent freedom from unequal stresses on the rope, may enable ropes to be used to raise materials with a factor of safety of 6, and then, provided parallel ropes can be made of sufficient strength, single winding with Whiting or Koepe sheaves would no doubt be successful. Taper ropes involve the use of cylindrical or preferably conical drums, and consequently the masses to be accelerated become very large. In the case of steam-driven plants these heavy masses are of advantage in steadying the jerky action of the steam-engine, but with electrical winding they seem to be an unnecessary expense, and it appears to the Author that the use of systems with sheave driving is likely to be largely adopted with electric motors in the future.

The majority of the winding-plants driven by electricity in Germany use the Koepe pulley. The question is a highly interesting one; but the advantages or otherwise of a sheave system as against cylindrical and conical drums, and the strength of ropes, together with the question of taper versus parallel ropes, are subjects that require special treatment, and hardly come within the scope of this Paper.

The utilization of the fly-wheel system, referred to later in the Paper, will no doubt have considerable effect upon the question of winding from deep levels, as it overcomes the objection to making provision for a heavy demand upon the power-supply during the period of acceleration. It would not be a difficult matter to arrange also that the acceleration periods of the two winders on double-stage winding do not entirely coincide; and thus the demand upon the source of supply would be considerably levelled up, and the economy over a single lift would be very considerable.

Electric Motors for Winding.

Winding-gears have not only to be started and stopped up to seventy times per hour, but they have to work preferably to fixed times for each trip, whatever the load may be.

Separately-excited continuous-current motors or three-phase asynchronous motors are probably the most suitable. They can be arranged to produce large starting-torques, and when the acceleration period is completed the attendant need not trouble regarding the speed, it will remain fairly constant whatever the load may be; in fact, a negative torque may arise, and energy may be returned to the generator.

In continuous-current motors with constant excitation the torque is proportional to the current in the armature and the speed is proportional to the difference of potential between the brushes. By varying the potential the motor will give a constant torque at varying speeds. If a constant difference of potential is maintained across the supply-circuit to the motor, it is necessary to have a controller to insert resistance in the armature-circuit. With the large motors required for winding, the controllers become very cumbersome. If two motors are used for the gear, a series-parallel controller as in traction may be adopted, but the connections and the contacts are heavy and inconvenient to manipulate. It is preferable to use if possible a variable pressure between the brushes, and this may be done either by a battery or by means of a special generator. An auxiliary starting-dynamo or booster could also be

used. The battery system, which is referred to below, involves much inconvenient switch-gear.

The special generator appears to be the best system, and the arrangement known as the Ward Leonard system is largely adopted and is described fully on p. 85. The Thury system is equally applicable and will no doubt be developed for the purpose, as it is well adapted and easy to control.

The starting of three-phase asynchronous motors with large torque without taking a heavy current from the supply-mains is somewhat difficult; the method is to insert variable resistances in the three circuits of the rotor. The type of starter adopted by the Allgemeine Elektricitäts Gesellschaft, of Berlin, for some large winding-gears, is a liquid one, and the liquid is pumped into a tank containing the contacts. The starting-lever alters the level of the liquid and the immersion of the plates, and consequently the resistance in each of the circuits is varied. This type of starter is giving satisfactory results at the " Preussen II " pit, near Dortmund.

Variation of Load in Winding.

Fig. 1 gives a fair idea of the variation of the load with an electrically-driven winding-gear. It is doubtful whether any public supply of electricity could possibly permit such great variation of demand upon the supply-mains.

The requirements of a mine, owing to the greater depths to which shafts have to be carried, increase yearly, and owners of coal-mines look to the possibility of raising 500 tons per hour. This means at least sixty to seventy winds per hour with 8 tons per wind, and a power of up to 3,000 HP. to 4,000 HP.; hence the call upon the sources of power is extremely heavy.

With electricity, the use of a storage-battery naturally suggests itself for the purpose of equalizing the demand. An electric winder with storage-batteries was devised by Messrs. Siemens and Halske, and the Author investigated the proposal in 1902 at the Düsseldorf Exhibition, where a complete winding-plant was erected. The switching-arrangements were very complete,[1] but there is little doubt that the very heavy current required at the moderate voltage necessary with continuous-current motors causes many difficulties. The Author believes that the scheme which the firm carried out at the Zollern II mine is now little used, and the Ilgner fly-wheel system has been utilized.

[1] For a description see *The Electrical Engineer*, vol. xxx (1902), p. 78.

Storage-batteries are largely used as a floating reserve of power for tramways and railways where the demand fluctuates greatly, though not to such an extent as in winding. It is possible that such a system could be effectively introduced in a colliery where more than one winder was in use. The total requirements would then be very large, and the actual power taken momentarily by any one winding-gear would not form a very large portion of the total. But the use of a battery for a single winder introduces difficulties with the starting-currents and the regulation; the battery itself is expensive to install and also to maintain, and the additional expense

Fig. 1.

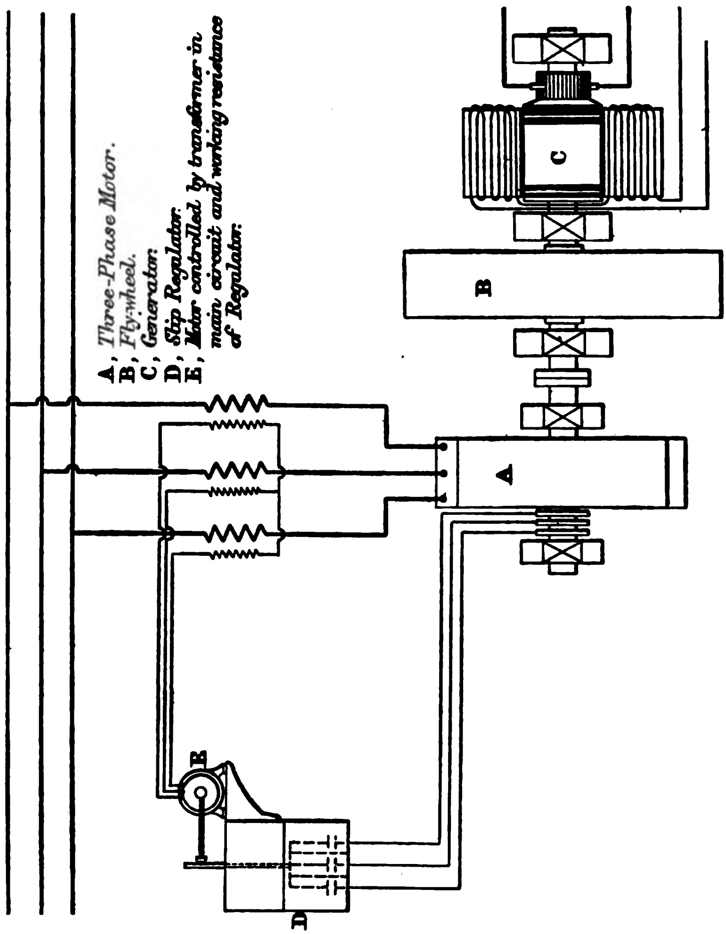
caused by such batteries would bring the total cost of electric winding to a very high figure.

The system introduced by Mr. Ilgner of Messrs. Siemens-Schuckert appears to get over the difficulty. The chief feature of the system is the use of a heavy fly-wheel, weighing in many cases up to 50 tons; and kinetic energy can be stored in this fly-wheel and taken out so as to meet the peaks and fill up the hollows of the curve of power taken by the winding. The wavy line at 400 amperes in *Fig. 1* shows the input to a generator with a fly-wheel when supplying an output varying from zero to 1,800 amperes.

In *Fig. 2* the supply of power is assumed to be on the three-phase system, and as this is most likely to be the usual form in which power will be received by a mine, it may be taken as a typical arrangement. The motor A receives the three-phase current at a

high pressure and would be of the induction type. It is coupled to the fly-wheel B and to the continuous-current generator C. The arrangement serves two purposes, for it converts the high-tension three-phase current into continuous current, which is the most suitable for the purpose of winding motors, and it enables power to

Fig. 2.



be absorbed and given out through the momentum acquired by the fly-wheel.

In order to produce the fly-wheel effect, arrangements are provided to keep the supply of energy to the motor constant within certain limits of speed of the fly-wheel. At the moment

when a heavy demand is made upon the generator C, the automatic slip-regulator D (in case of a three-phase motor) inserted in the starting supply-circuit to the motor A is operated through the small motor E, which prevents more than a fixed amount of energy from being taken from the supply-circuit; the balance of the energy required by the generator is obtained from the fly-wheel, which consequently loses speed. As this speed is reduced, the regulator is operated so that, when the lowest speed is reached, the motor is permitted to increase, if necessary, its demand upon the main supply. When the generator ceases to be called upon to give energy, and in the case of electric winding will receive energy from the winding-motor during retardation, the regulator operates so that the excess of energy goes into the fly-wheel, the main supply being limited, and the speed rises to its maximum again.

An alternative to the Ilgner system has been devised by Mr. Creplet. In this system the fly-wheel is not coupled to the motor-generator, but is attached to a third dynamo (*Fig. 3*). This dynamo is in series with the generator and the winding-motor, so that any excess of current goes into the fly-wheel during periods of small demand and is taken out during periods of large demand. Hence the speed is independent of the main motor and may be varied between such wide limits as 50 per cent. The weight is materially reduced and much loss in friction is avoided.

The difficulty appears to be the necessity for two hand adjustments, and the addition of a third dynamo increases the plant requiring attention.

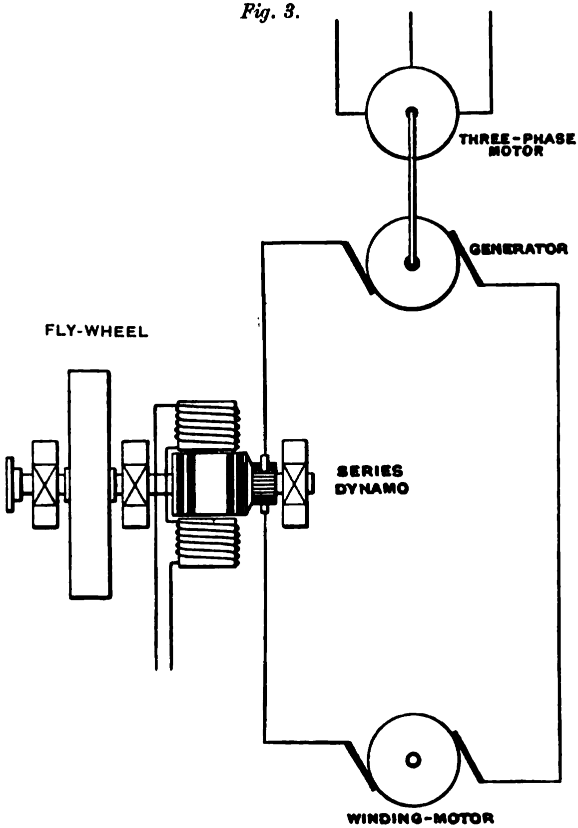
Starting and speed-control of the winding-motor itself is effected by means of the Ward Leonard system, which alters the excitation of the generator: the range is, by these means, so manipulated that the generator can be used to give any current and any electromotive force that may be required, and by reversing it is also used as a motor.

The Ward Leonard system of control[1] consists primarily of a shunt-wound generator and a shunt-wound winding-motor, both separately excited. The field of the generator is variable, while the field of the winding-motor is kept constant (*Fig. 4*). By suitably varying the exciting current in either direction, the generator will produce current at variable pressure in a positive or negative direction. The armature of the winding-motor is connected in series with the armature of the generator, and thus, when the generator is excited, current will flow, and the motor will be started

[1] See Minutes of Proceedings Inst. C.E., vol. cxlix, p. 71.

at the maximum torque in either direction according to the direction of the exciting current. As the speed of the motor increases, its counter electromotive force rises, and the pressure of the generator must be increased to keep up the maximum current. This is done by increasing the quantity of exciting current flowing through the generator, by means of the driving-lever. This goes on until the

Fig. 3.



speed of the motor has risen to its maximum, and remains so until it is necessary to shut down the motor. When this is required, it is only necessary to reduce the exciting current in the generator by moving the driving-lever to enable the counter electromotive force of the motor to overcome the electromotive force of the generator-circuit, and then the motor will return current into the generator, and the energy so returned is taken up in the fly-wheel.

Some careful measurements were carried out at Karwin colliery, in Germany, where the three-phase motor received about 400 HP. from the outside mains, whereas the maximum demand upon the winding-motor was as much as 1,350 HP. In this case the fly-wheel

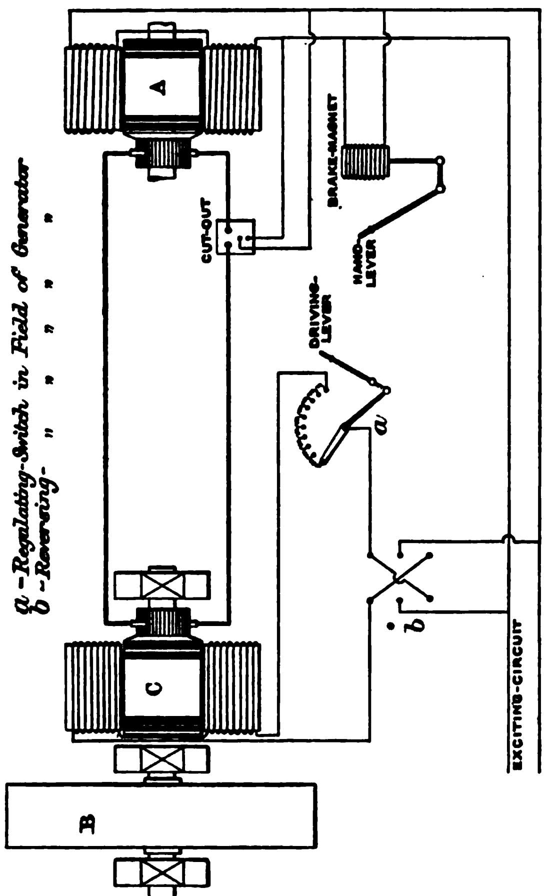


Fig. 4.

a -Regulating-Switch in Field of Generator
b -Reversing- " " " "

A, Winding-Motor; B, Fly-wheel; C, Generator.

weighed 28 tons, and was calculated to supply the deficiency while losing about 8 per cent. of its speed. It was made of cast steel, and the bearings were supplied with oil under a pressure of about 120 lbs. per square inch. When the motor-generator and fly-wheel were taking 340 kilowatts the losses appear to have been—

Fly-wheel alone	21 kilowatts	= 6·2 per cent.
Motor-generator alone . . .	10 "	= 2·9 " "
Fly-wheel and motor-generator	37 "	=10·8 " "

In the case of the fly-wheel set at the "Espérance" pit, Professor Habets ascertained that the loss due to friction and windage amounted to 17 kilowatts. The fly-wheel weighed nearly 40 tons, and the speed varied from 314 to 285 revolutions per minute. This loss represented about 4·1 per cent., the input of the induction motor being about 240 kilowatts. But this test was obtained from the actual electrical energy supplied to the combination when running with no load on the generator, and assuming an efficiency of 60 per cent. for the motor at the reduced load.

Storage of Energy in a Fly-Wheel.

The amount of energy available for storage in a fly-wheel depends upon the period of retardation and the period of decking.

It should not be difficult to design the winding-gear so that a constant load is kept on the prime motor, and all energy required for acceleration is obtained from the energy stored in the fly-wheel.

Assuming it is required to lift 5 tons each trip from a depth of 2,100 feet, and the total time permitted, including decking, is 75 seconds, the useful work is equal to 23,520,000 foot-lbs. in 75 seconds, or an average of 313,600 foot-lbs. per second. Assuming the time for retardation and for decking is 30 seconds, the energy available for storage in a fly-wheel should be $313{,}600 \times 30 = 9{,}408{,}000$ foot-lbs.

If the maximum speed of the fly-wheel motor-generator is about 450 revolutions per minute, and allowing a loss of 30 revolutions, it will be found that a fly-wheel of 30 tons, having a diameter of about 12 feet, would give about 9,000,000 foot-lbs.

The output of the prime motor of the combination would be, if no losses occurred—313,600 foot-lbs. per second or 570 HP.-seconds.

The energy available for starting would thus be 570 HP.-seconds plus about 9,000,000 foot-lbs. obtainable from the fly-wheel, and on this basis the rate of acceleration may be determined.

II.—Supply of Power to Mines.

At the present time, in Great Britain, Germany, and South Africa, the supply of electricity in bulk to large users for power purposes is attracting much attention. In the north of England, the Newcastle Company are supplying many large power-users at a very low price; and it is claimed that it is impossible for large consumers to generate electricity at their own works at a lower rate than that at which it is purchasable from the Newcastle Company. A similar scheme, though with a different object in view, is being promoted for London. The rates proposed vary according to the load-factor, and the following Table gives a proposed scale, which is based on a charge of £3 12*s.* per kilowatt demanded, and 0·20*d.* per unit consumed:—

Hours per Day.	Load-Factor. Per Cent.	Price per Unit. *d.*
3·00	12½	1·0
5·00	20	0·68
8·00	33⅓	0·50
12·00	50	0·40
24·00	100	0·30

These prices are for high-pressure current, and the net cost to a mine for transformed current would be slightly higher.

It appears to the Author that in coal-mining work the load-factor is not likely to exceed 40 per cent., and hence the minimum average cost per unit sold to a mine in this country would not be less than 0·45*d.* In the case of gold-mining, owing to the heavy demand for power for milling and other purposes, it is probable that the load-factor will be above 40 per cent.

The cost of equipping a generating-station for supplying electricity to a mine depends largely upon the place in which the mine is situated, and also upon the prime mover to be adopted. As large plants only need be considered—for they alone are likely to compete with supply from an outside source—it is not necessary to go into the question of the use of oil-engines, which are not yet made in large sizes; it is sufficient to consider steam- and gas-engines. Further, in the case of gas, the size of the plant would preclude the use of the suction-gas system, so that producer-gas alone need be considered.

The Author estimates the expenditure of capital required to equip a generating-station of 3,000 kilowatts and of 6,000 kilowatts either

with steam-turbines or with gas-engines using ordinary producer-gas to be as follows:—

Output.	Gas-Plant.			Steam-Plant.		
	£	s.	d.	£	s.	d.
3,000 kilowatts	17	0	0	11	0	0
6,000 ,,	15	10	0	10	0	0

The actual cost of the power-station recently erected at the Powell Duffryn colliery in South Wales has been given as £11 10s. per kilowatt.[1] This station consists of a 1,500-kilowatt and two 750-kilowatt sets, with boilers and horizontal cross-compound jet-condensing engines. The station is of simple design, and may be taken as a typical example of what can be done at a colliery. Gas-engines are now being installed by the same company at other collieries, and it will be interesting to see the results in the cost of installation and working.

The greatest development of gas-engines is taking place in connection with coke-ovens and with the waste gas from blast-furnaces. The Mond producer is also being largely used where there is a fair chance of a market for the by-products and where low-grade bituminous fuel is obtainable. The Author understands that in the Westphalian district a company has been formed, and is at work to some extent, for the purpose of taking over all the waste gases from the various blast-furnaces and coke-ovens, and erecting isolated gas-engines and plant to generate electricity for power purposes. All the plants will work in parallel and will supply electricity in bulk to anyone in the district.

Both two-cycle and four-cycle gas-engines are used for large installations, principally 1,000 HP. per cylinder. The Author is not aware that engines larger than 2,000 HP. are used in general practice. The tendency appears to be towards single-crank units as being simpler and suitable for electrical work, and there seems to be no difficulty in parallel running.

Cost of Electricity.

The cost of electricity depends upon the load-factor, and this question has also a great deal to do th the system to be adopted. The use of gas produced by coke-ovens in a colliery would conduce to very economical generation of electricity, provided a constant demand is made upon the generating-plant. This means a high load-factor; and, as gas cannot be economically stored, there is

[1] Journal of the Institution of Electrical Engineers, vol. 36 (1906), p. 497.

little possibility of the best results being obtained when the load-factor is very low.

A gas-engine will give 1 kilowatt from about 100 cubic feet of producer-gas, and a ton of slack will produce 120,000 cubic feet to 150,000 cubic feet. Hence 1 ton of slack should produce 1,200 kilowatt-hours to 1,500 kilowatt-hours or units. It is difficult to obtain, even under the best conditions, steam-engines or steam-turbines which, when condensing, will give 1 kilowatt-hour for 2¼ lbs. of slack, allowing 13½ lbs. of steam per kilowatt-hour and 6 lbs. evaporation per pound of coal in the boilers: hence 1 ton of slack will produce with a steam-engine less than 1,000 kilowatt-hours; and on these figures it is obvious that a gas-engine is more economical of fuel than the steam-engine.

Fuel, however, is not the principal item of expenditure. The cost should be divided into the following three items:—

(*a*) Interest and depreciation on capital.
(*b*) Fuel.
(*c*) Wages and repairs.

The Author places interest and depreciation as the first essential item for consideration, as capital in mines is generally wanted for development. As shareholders look for a high rate of interest from mines which have a short life, interest on capital is a very important matter. The Author does not think that an average of 7½ per cent. is excessive. There is also depreciation, for which 2½ per cent. is the minimum that should be allowed. Hence every pound sterling spent upon an installation in a mine should be reckoned to cost 2*s.* per annum for interest and depreciation when working out the annual cost.

The following Table shows the effect of 10 per cent. on the cost per unit with various load-factors[1]:—

Cost per Kilowatt.	10 per Cent. per Annum.	Cost per Unit in Pence with different Load-Factors.			
		75 per Cent.	50 per Cent.	30 per Cent.	20 per Cent.
£	£	*d.*	*d.*	*d.*	*d.*
10	1	0·06	0·08	0·13	0·2
20	2	0·11	0·16	0·26	0·4

As regards fuel it is exceedingly difficult to give any accurate figures, for the cost depends not only upon the mines' local prices

[1] The load-factor is based upon 250 working-days, or 6,000 hours.

for fuel used but also on the system adopted. However, the following Table gives the cost of fuel at various prices with steam-engines, and the Author considers that gas-engines may safely be taken at about 25 per cent. less.—

Load-Factor.	Coal per Unit.	Cost per Unit in Pence according to Price of Coal per Ton.			
		4*s*.	6*s*.	8*s*.	10*s*.
Per Cent.	Lbs.	*d*.	*d*.	*d*.	*d*.
75	3·0	0·06	0·10	0·13	0·16
50	3·5	0·07	0·11	0·15	0·18
30	4·0	0·08	0·12	0·17	0·21
20	4·5	0·09	0·14	0·19	0·24
10	5·0	0·10	0·16	0·21	0·27

It will be observed that a fair quality of coal is assumed. If, however, poor slack is used, its price would probably be less than 4*s*., so that the net result would be the same.

The third item is wages and repairs, which also is a very variable figure; and widely different ideas exist as to the technical staff required. The Author considers that the annual cost in a mine is largely independent of the load-factor. Whatever the work, a night and a day staff are practically necessary. Even if plant is not working at full load it is running, and it requires attention; and repairs are as likely to be needed with constant half-load working as with constant full-load working.

The following may be assumed:—

	Annual Cost per Kilowatt installed. £ *s*. *d*.
Large plants	1 0 0
Medium plants (3,500 kilowatts)	1 10 0
Small plants (1,000 kilowatts)	2 0 0

The costs are thus:—

Cost per Annum.	Cost per Unit in Pence with different Load-Factors.			
	75 per Cent.	50 per Cent.	30 per Cent.	20 per Cent.
£ *s*. *d*.	*d*.	*d*.	*d*.	*d*.
1 0 0	0·06	0·08	0·13	0·20
1 10 0	0·09	0·12	0·19	0·30
2 0 0	0·12	0·16	0·26	0·40

From the above Tables a rough idea as to the maximum cost per unit may be obtained. On the assumption that a mine has a demand

for 2,500 kilowatts and coal is 6*s*. per ton, the cost per unit with load-factors of 20 per cent. and 50 per cent. would be:—

	Load-Factor 20 per Cent.	Load-Factor 50 per Cent.
	d.	*d.*
Interest and depreciation	0·20	0·08
Coal (steam) at 6*s.*	0·14	0·11
Wages, etc.	0·30	0·12
	0·64	0·31

The margin below the price charged by a power-company, with a 20-per cent. load-factor, would probably be so small that it would be better policy to purchase current from them. But it may be much higher, according to the capital expenditure and the cost of fuel and wages. In the case of a mine in South Africa the cost may easily reach 1·00*d*. per unit. Mr. Sparks states in the Paper already referred to that in the case of the Powell Duffryn colliery the cost with a load-factor of 37 per cent. has been 0·365*d*. and he expects it to be reduced to 0·3*d*.

A gold-mine, which requires a very large amount of power on the surface for stamps, elevators, etc., as well as for winding and washers, would probably have a high load-factor. But usually it has to pay heavily for coal and labour, and for interest, etc., and it appears hardly possible that the price per unit could be brought below 0·75*d*.

The following figures, which show the high cost of separate engines, have been obtained from an actual mine in South Africa:—

	Cost per HP.-Hour.	Equivalent Cost per Unit.
Winding-engine	1·3	2·0
Mill-engine	0·528	0·814
Lighting-engines	0·630	0·970
Compressors	0·510	0·785
Pumps	0·723	1·1

In this case the mill and the compressors are working practically at constant load, hence their superior economy.

The Author is indebted to Messrs. Siemens Brothers & Co., and to the Allgemeine Elektricitäts Gesellschaft, for facilities for visiting various German collieries and for much information.

The Paper is accompanied by five drawings, from which the Figures in the text have been prepared, and by the following Appendixes.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

DESCRIPTION OF WINDING-GEAR DRIVEN BY CONTINUOUS-CURRENT MOTORS.

The installation at the Mathias Stinnes colliery at Carnap, near Essen, is a very complete one. The energy is purchased from the Essen town generating-station, being transmitted about 6 miles to the colliery, at a pressure of 5,000 volts, 50 periods.

There are four winding-plants, each designed to lift 4·8 tons (10,750 lbs.) from a depth of 866 yards at a maximum speed of 46 feet per second. The total amount of coal to be raised by each winder is 800 tons in 8 hours.

The Koepe type of pulley has been adopted, the diameter being 21 feet, with a rope 2·32 inches in diameter. Two continuous-current motors are coupled direct to each pulley, and they work in series with each other.

The continuous current for the eight winding-motors is obtained from four Siemens-Ilgner fly-wheel converters. These converters are coupled in pairs, each pair being made up of two three-phase 5,000-volt induction motors and four continuous-current dynamos with two fly-wheels. Each fly-wheel weighs 40 tons.

The speed of the converters varies between 310 and 375 revolutions per minute. The maximum current taken by each induction motor is 53 amperes. Each continuous-current generator is capable of giving 2,100 amperes at 400 volts.

Two dynamos are connected in series, and they supply current on the Ward Leonard system to the two motors (also in series) on each winding-gear.

The slip regulator in connection with the three-phase motor is put into action through a motor which varies the contacts as the current to the motors rises or falls below a fixed amount. The action is quite automatic.

There are only two levers controlling each winding-gear; the one on the right hand of the driver controls the motor, and that on the left hand controls the brake. The two levers are interlocked, so that when the motor is in action the brakes are released. The brakes are operated by compressed air. The movement of the right-hand control-lever merely varies the exciting current of the two converter dynamos. There are no heavy resistances, as the current to be varied is very small. The field-rheostat is operated by a small pinion and sector moved by a rod attached to the lever. It is provided with a large number of steps, and small gradations in speed are obtained. Any speed is easily obtained, and the control is rapid.

If the exciting-current is reduced so that the electromotive force of the generators is brought below the back electromotive force of the winding-motors, the latter will act as generators and regenerate the energy while tending to bring the winding-gear to rest.

A stop is automatically operated in the frame of the control-lever, which prevents the lever from being pushed beyond a point corresponding with the proper speed when men are being lifted.

The lever of the brake is supported by compressed air acting upon the piston of the brake-cylinder, which is fitted with a three-way cock through which connection is made either with the air-receiver or with the atmosphere. Should the pressure

fall, or a leak occur, the brake acts automatically on the drum and a counterweight falls and throws over an emergency switch cutting the motor out of circuit. The three-way cock can also be operated by hand or by the depth-indicator, and the brake caused to act.

Messrs. Siemens-Schuckert have devised a depth-indicator which forms part of the controlling and brake system. It consists of two vertical screws driven by gearing from the main winding-shaft. At the bottom of the frame is a wheel which makes one complete revolution during the lift. The wheel has in its periphery four cams which engage in rods connecting with the control and brake-levers. These cams are so shaped that it is impossible for the driver to start the gear too quickly, and they also bring the control-lever automatically to the "off" position and apply the brake when the wind is completed.

The movement of the cam-wheel is thus synchronous with that of the indicator, and controls automatically the position of the control-lever, and consequently the speed of the cage. The control-lever is connected to rollers, which press against the cams when the driver moves the lever. The variations in the profile of the cams limit the distance through which the driver can move his lever, according to the position of the cage in the shaft. At the beginning of the wind the driver moves his lever in the required direction, but without being able to pass the position fixed by the corresponding cam. The winder starts at the speed corresponding to this position; the cam-wheel simultaneously rotates and allows of the lever being further advanced, so that the speed is increased, and so on, until the maximum is reached. The driver is always able to draw back his lever for reducing the speed, but if he forgets to do this at the right time towards the end of the wind, the lever is returned automatically by the cam and the speed of the winder is re-started at a prescribed rate.

The driver retains the power of carrying out the necessary operation at low speed up to the moment when the cage passes the bank. At this instant the profile of the cam makes an abrupt change and rapidly returns the control-lever to the off position. At the same instant a stop works upon an unlocking gear at the end of the run, which immediately puts on the safety-brake, and the winding-engine, which has already been slowed down, is brought entirely to rest.

Fig. 5 shows the arrangement of half the plant at this colliery. Two of the gears are by Messrs. Siemens-Schuckert, one by the Allgemeine Elektricitäts Gesellschaft, and one by the Lahmeyer Company.

APPENDIX II.

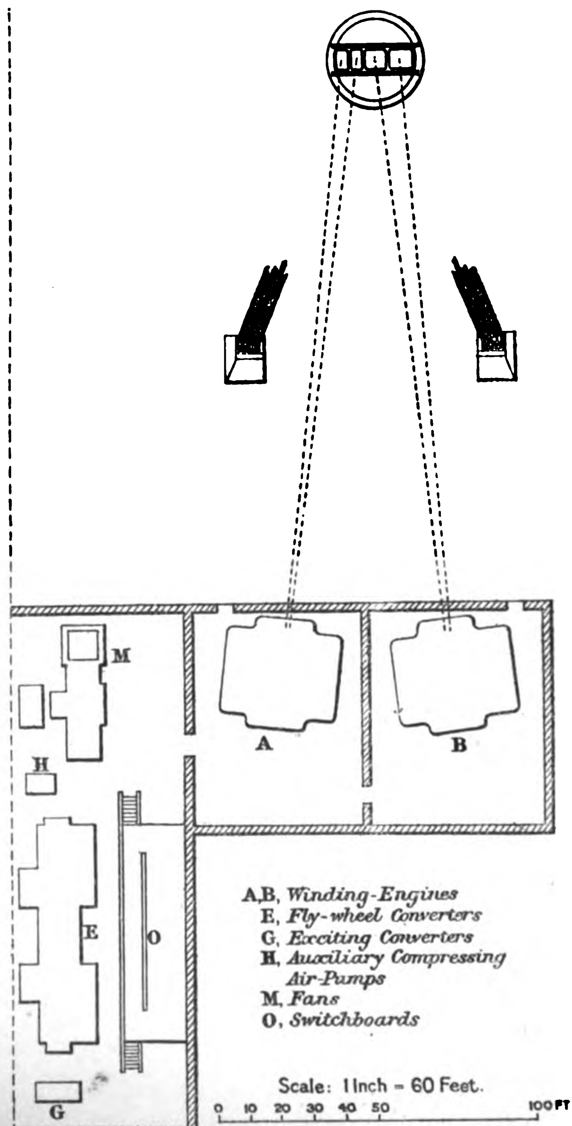
Winding-Gear driven by a Three-Phase Alternating-Current Motor.

A typical example of this method had been erected at the "Preussen II" pit of the Harpener Company, near Dortmund, by the Allgemeine Elektricitäts Gesellschaft. The plant has been designed to wind 100 tons of coal per hour from a depth of 765 yards.

A Koepe pulley is used, and the weights of the moving load are:–

Coal	2 tons	4 cwt.
Four tubs.	1 ,,	8 ,,
Cage	3 ,,	16 ,,
Rope	4 ,,	18 ,,

Fig. 5.


M
H
E
O
G
A
B
A,B, *Winding-Engines*
E, *Fly-wheel Converters*
G, *Exciting Converters*
H, *Auxiliary Compressing Air-Pumps*
M, *Fans*
O, *Switchboards*
Scale: 1 Inch = 60 Feet.
0 10 20 30 40 50 100 FT

The winding cycle is: accelerating 16 seconds, full speed 27 seconds, retarding 18 seconds, decking 17 seconds.

The maximum power required at starting is about 1,380 HP., while the power during full speed is 650 HP. The full speed is 52 feet per second when winding coal.

The Koepe pulley has a diameter of 19 feet 8 inches, and the rope is 1·77 inch in diameter. The brake consists of two heavy slippers on each side of the pulley, and they are operated by compressed air.

The motor is mounted on the same shaft as the Koepe pulley, and is of the three-phase induction type, provided with slip-rings in the rotor-circuit. The three-phase current to the motor is at 2,000 volts, and is generated by special plant erected in the colliery. The pressure in the induced rotor-circuit is 300 volts.

The current from the generators is brought through high-tension fuses first to an emergency-switch, which can be operated by the brake-lever. It proceeds thence to a reversing-switch for altering the direction of rotation of the motor, and the switch is operated by the driver. It has three positions; the middle position cuts off current entirely, and by moving the lever to the left or right the direction of rotation of the winding-gear is altered. The current then goes direct to the stator of the motor. The high-tension apparatus is thus very simple.

The starting is operated entirely by a liquid resistance in series with the rotor-winding. Each of the three phases of the rotor goes to a resistance-plate suspended in a tank which has a reservoir below. A solution of soda is kept circulating from the reservoir through the tank back to the reservoir by means of a small rotary pump operated by an independent three-phase circuit.

The upper tank is provided with regulating-valves at the bottom, which allow the liquid to accumulate when closed, and so reduce the resistance of the plates and allow a passage of current between the plates, thus permitting the motor to speed up. As the liquid rises, so the resistances are reduced, and the current in the rotor-circuit gradually reaches a maximum when the liquid overflows and the motor runs at full speed.

The lever regulating the opening and closing of the tank-valves is geared to the driving-lever in such a way that the driver first sets the lever forward or back, according to the direction of rotation, and he is then able to move the lever through an arc at a different angle and operate the tank-valves. Similarly he cannot reverse the direction of current without first gradually stopping the motor.

The speed of starting is sufficiently independent of the driver to prevent him from starting too quickly, though he is able to start as slowly as he likes. The safety-arrangements are very complete. The compressed-air brake on the pulley is thrown in by a hand-lever, and it is also controlled by the depth-indicating gear in case of overwinding. This gear also operates upon the emergency main switch. In the event of difficulty with the compressed air, a foot-lever brake is also provided. If the current is interrupted accidentally, an electromagnetic device releases a weight which actuates the rod of the compressed-air brake.

APPENDIX III.

Tests of Electrically-Driven Winding-Gear at the Wintershall Colliery, Heringen.[1]

The depth of the mine is 475 yards, the maximum quantity lifted per wind is 2·00 tons, and the maximum velocity 26¼ feet per second.

The acceleration was 1¼ foot per second per second, and the retardation 3·9 feet per second per second.

The time for each wind was 66·7 seconds, and the time for decking was 23·3 seconds.

The original intention was to wind only 1·75 ton, but it was found possible to work up to 2·00 tons and to get forty-six winds per hour.

A Koepe pulley, 13 feet 9 inches in diameter, and a rope 1·3 inch in diameter, is used, with a continuous-current motor direct coupled to it.

The Ward Leonard system, with Ilgner fly-wheel converter, has been adopted, and consists of a 250-HP. three-phase motor, a 16-ton fly-wheel, and a 260-kilowatt generator (continuous rating), all running at 375 revolutions per minute. The diameter of the fly-wheel is 15 feet. A compound-wound exciter (of 10 kilowatts capacity) is coupled direct to the converter-shaft. A brake is fixed to the circumference of the fly-wheel to stop it quickly if necessary.

A test of the consumption of energy over 8 hours showed a total consumption of 1,549 kilowatt-hours by the three-phase motor when 657 tons was lifted, and the number of winds was 365. This consumption includes all the electrical losses on the fly-wheel converter as well as friction-losses.

The average energy per wind was thus 4·24 kilowatt-hours or 5·77 HP. The theoretical energy required to lift 1·8 ton per wind is 2·94 HP. Hence the useful effect of the winding plant is $\frac{2\cdot 94}{5\cdot 77} = 0\cdot 51$.

The average energy taken by the winding-motor was found to be 3·03 kilowatt-hours, and thus the efficiency of the converter was 72 per cent.

The winding-motor itself had an efficiency of 87 per cent., while the average loss in shaft-friction was 0·63 HP. per hour.

It was also found that the fly-wheel converter took 13 kilowatts running at full speed and excited, but without converting energy.

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[1] A description of this gear and of the tests will be found in *Glückauf*, 1906, p. 965 from which these particulars are derived.

Discussion.

The PRESIDENT remarked that the importance of mining, and of everything connected with it, to British industries in general was so great that it was particularly appropriate the "Proceedings" of The Institution should contain Papers dealing with the subject. Mr. Kellow's Paper appeared to be the first communication to The Institution on the application of electric power to slate-mining. He was sure the members would pass a very hearty vote of thanks to the Authors for their interesting Papers. The President.

Mr. KELLOW did not think that the hydro-electric plant described in his Paper had much claim on the attention of the members in point of magnitude; for, in comparison with the scores of thousands of horse-power heard of in connection with hydro-electric plants in foreign countries, 400 HP. was an insignificant figure: but some interest might attach to the installation from the fact that it was a complete power-scheme, and from the variety of the problems involved in the design. It included storage of water, transmission of water to a generating-station, the hydraulic generation of power, electric generation of power, transmission, transformation, distribution, and the conversion of the electrical energy into mechanical power. The arrangements described started with the rain-drops and finished with the motor-shaft. One of the principal objects aimed at throughout the system was the attainment of high efficiency, and he thought in that respect the results attained were not unsatisfactory. It would be observed from the diagrams that, when the motors were working at full load, the fairly high efficiency of 64·43 per cent. of the potential energy in the water in the reservoir, delivered on the motor-shaft or at the lamp-terminals, was obtained. One of the principal factors which had contributed to that result was the fact that the flow of water from the reservoir was practically regulated by the electrical controlling-devices of the mine; in other words, water was used in proportion to the power consumed at the mine, and none was wasted. In some cases the results of the hydraulic tests had clashed with his preconceived ideas on the subject, particularly with regard to peripheral speed. It was impossible, however, to get over the facts, and if facts and theories clashed, the theories must be modified to suit the facts. The ground covered by Mr. Preece's Paper and by his own differed widely in the respect that the power required generally in slate-mines was very small in comparison with the large power required in coal-mines. Mr. Kellow

Mr. Preece. Mr. PREECE explained that he had purposely omitted from his Paper details with regard to the costs of electrical winding, because it appeared to him that the question of the cost was not of very great importance. The cost of winding ore by steam-power was about ½*d.* per ton raised; and even assuming the cost of electricity to be double that of steam, it only increased the price of any ore raised to the surface by ½*d.* per ton, which was quite a trifling fraction of the total cost in dealing with a ton of ore—whether coal, gold, or whatever it might be. Electrical engineers claimed that the advantage of electrical working was the increased efficiency, because by using electricity it was possible to increase the quantity of ore raised in an equal time by about 10 per cent. It must also be recollected that frequently half a million sterling was sunk before a ton of ore could be treated on the surface, and so small an increase in the cost of raising a ton of ore would have no appreciable effect on the total cost of treating it.

Mr. Denny. Mr. G. A. DENNY desired to raise a few points suggested by Mr. Preece's paper. The first cost actually depended on locality. An engine which cost, say, £1,000 in England, might be expected to cost two to two-and-a-half times that amount by the time it was erected in Johannesburg. Two built-in boilers, suitable for ordinary winders, one boiler always spare, with feed-pumps, steam-mains, and water-supply, would cost £2,000. A complete electrical gear to handle an equivalent load would probably cost, ready to run, about £1,000. If power were bought from an outside source no steam-raising plant and accessories would be required, thus securing economy in capital expenditure, and a saving in interest, redemption, and depreciation. Regarding the consumption of steam in winding-engines, it might be taken that the ordinary intermittently-running non-condensing engine would not do better than 50 lbs. of steam per shaft horse-power-hour. This had been proved by various tests known to him. Instances of better results had been obtained, particularly in a test recently made by Messrs. Robesan and Behr. In this case the engines ran—he was speaking from memory—about 50 per cent. of the possible time of the test, and were compound condensing engines. The results of the test showed a consumption of about 30·3 lbs. of steam per shaft horse-power-hour, or 25·2 lbs. per indicated horse-power-hour, which were surprisingly low figures. Steam-consumption tests made on certain Zollern electrical winders had shown a consumption of 26 lbs. per shaft horse-power-hour, and 18·16 lbs. per kilowatt-hour. There was a marked difference, however, as might have been expected, when the winders were running very infrequently on the night shift, the consumption rising

to 122·13 lbs. per shaft horse-power-hour, and 20½ lbs. per kilowatt-hour. With regard to winding from deep shafts, the deep-level conditions referred to by Mr. Preece were typified on the Witwatersrand. The question of the economy of the fly-wheel system was largely one of constancy of winding. In very intermittent running, which was a usual condition during the larger portion of the time, the constant loss, due to the energy-consumption of the fly-wheel itself, would render it a very uneconomical system, particularly if power were purchased from an outside source; and there was no reason to consider the comparative station-installations required respectively with and without the fly-wheel set. It was rather, however, in connection with the inclined haulage in the mine proper to the deep-level shafts that the difficulties of a suitable winding-gear were apparent. In the early stages of the mine the hauls would necessarily be short and intermittent, and acceleration would form a very undesirable portion of the total haul, thereby raising unduly the average energy-consumption and the cost. The fly-wheel system would also involve large extra expenditure and capital cost in the underground station, the interest on which would be a heavy charge on the tonnage raised. Mr. Preece stated that the cost of electricity depended entirely upon the load-factor. If this statement meant the cost to the consumer, in Mr. Denny's opinion it was hardly correct. The cost would vary considerably, depending on whether it was possible to concentrate the power-requirements to a size that would give a good power-factor, or whether the conditions necessitated the use of numerous motors of small powers, in which the power-factor was low. The two cases might represent, together with line-losses, etc., very material differences in total cost to the consumer. Mr. Preece placed interest and depreciation as the first essential item for consideration in the cost of electricity. Here Mr. Denny entirely agreed with him, but he would add the item of redemption; it would probably be of interest to members to know that neither interest nor redemption-charges were recognized on the Rand in connection with electrical, or indeed, any working-costs. The power-cost was therefore made up minus these items. He hardly followed Mr. Preece when he said that he did not consider 7½ per cent. an excessive rate of interest on a mine with a short life. The average life of a mine at the Rand would be, say, 20 years, therefore a short life would be, say, 10 years. If, therefore, an investor received only 7½ per cent. interest for 10 years on an investment of £1,000, he would receive in all in return only £750, that was, he would lose £250 of his capital, and, assuming he did not reinvest his money, the interest on £1,000 for 10 years. The investor must receive 7 or 8 per cent. as a Mr. Denny.

Mr. Denny. minimum on his investment in a mining risk, and must also create a sinking-fund for replacement of capital. At 8 per cent. for interest and 3 per cent. for redemption-fund, the investor of £1,000 in a mine with 10 years' life would require an annual dividend of £167, or £1,670 in 10 years. He did not agree with the Author's figure of $2\frac{1}{2}$ per cent. for depreciation on a "short" life. On a 10-year life the depreciation-fund would have accumulated only to the extent of 25 per cent. of the outlay; hence 75 per cent. would be lost, with the exception of the amount for which the machinery could be sold. Depreciation should, in his opinion, figure at 10 per cent. under the conditions assumed; so that Mr. Preece's Table, showing the cost per unit with various load-factors, allowed merely for redemption of capital outlay without interest, and therefore nullified his own view as to the importance of interest and depreciation in the cost of electricity. The value of the total cost for interest, coal, and wages tabulated by Mr. Preece was likewise vitiated when applied to short-life mines. As to whether a mine should generate its own power, or purchase it from outside sources, it must be remembered that the production and distribution of power was the sole purpose of the supply-company, and was a secondary consideration with the mine. The supply-company might be able to introduce a diversity-factor, and thus keep down its main installation-cost, and average its load-factor. The average gold-mine, being unable to introduce a diversity-factor, had to arrange for one unit rated at maximum demand, and the average condition was one of extreme under-load. The actual conditions were, as he had experienced, that a mine secured an efficiency of only 45 to 55 per cent. from its electrical plant. Were the mine to purchase from an outside supply, it would pay for current generated at high efficiency, and would thus greatly reduce the total electrical horse-power consumed. To Mr. Denny's mind the chief recommendations for purchasing power from an outside source were:—

(1) The station would generally be large enough to take care of the sudden demands of a mine, which it might be difficult for the mine itself to do unless it installed power out of proportion to the average demand.

(2) The mine was not called upon to sink capital in plant for the generation of power, and thus was not required to lessen its cash resources.

(3) The losses in generation, transmission, etc., were borne by the outside supply-company, a matter of great moment to the average mine, which in the nature of the case suffered under conditions of bad load and bad power-factors.

(4) The effective power required being secured at higher average efficiency, the total current consumed would be less when bought from an outside source. Mr. Denny

Mr. Preece was optimistic in his estimate of the cost of power in South Africa. The average cost per effective horse-power for winders, including interest and redemption, was not less than £100 per annum, or, taking the efficiency of the winders at 80 per cent., the cost per indicated horse-power was £80 per annum. In connection with the figures which Mr. Preece gave for a mine in South Africa, he stated that the mill and the compressors were working at practically constant load, thereby explaining the comparatively low cost per horse-power-hour. Whilst it was true that mill-engines ran usually at constant load, the air-compressors did not. They had in fact a very fluctuating load when running, were stopped generally for 4 hours per day between shifts, and were shut down every Sunday. Cylinder-condensation, a bad load-factor, and intermittent running, were therefore all present, and would certainly effectually prevent economical working. The air-compressor, indeed, formed one of the strongest proofs of the advantages of outside electrical supply. The losses in air-compression, transmission, and conversion to work at the rock-drill or pump, were such that the efficiency secured represented only 6 to 10 per cent. of the original power of the steam-engine. The cost per effective horse-power could easily be imagined. If the mine were to purchase electrical power from an outside source, and compress air in small machines near the required points, the efficiency at the rock-drill bit could be raised to 30 per cent. at least. Similarly, the pumping efficiency could be raised by the use of electrical energy. The result would be a considerable saving to the mine.

Dr. R. Herzfeld was sorry that he could not agree with Mr. Preece on the importance of the question of cost. He had found that the question of cost was gone into thoroughly by coal-owners when dealing with the question of steam versus electricity. He thought the success of electrical winding was entirely dependent on the question of power-supply, and there could only be an improvement if this power-supply was carried out on strict business lines. It did not matter whether this business was in the hands of a separate company or of a separate department of the colliery-undertaking. The most important point seemed to be that the plant should be sufficiently expansible to deal with the varying conditions which occurred in the course of the week and the year. Only under these conditions would it be possible to give the power-consumer good and attractive conditions for his current. But if all these conditions were fulfilled Dr. Herzfeld.

Dr. Herzfeld. and no waste took place in the generating-station, electrical winding had one great advantage which was perhaps so far not sufficiently recognized and which he would like to mention. It removed from the shoulders of the colliery-owner an onus of great importance, namely, the readiness to start winding at a moment's notice, even at long intervals and between shifts. On this point the authorities would not give way, and it was certainly necessary for the safety of the mine and of the miners to be ready to start a winding-engine at a moment's notice. There were not many figures available showing the losses the collieries suffered in this connection, by being bound to keep their steam-plant, from the boilers to the jackets of the cylinders, in a state of readiness for immediate starting all through a Sunday. One well-managed colliery in Wales gave the figure of 5 tons of coal as being required for heating the steam-jackets of one winding-engine during 24 hours, which showed that the aggregate losses during the year were considerable. The figures in the following Table referred

Day.	Steam-Consumption		HP.-Hours in Mineral raised.	Steam Consumption per 1 HP.-Hour in Mineral raised	
	Without Condensing Losses in Pipes.	With Condensing Losses in Pipes.		Without Condensing Loss in Pipes.	With Condensing Loss in Pipes.
1906.	Kilograms.	Kilograms.		Kilograms.	Kilograms.
Thursday, 28 Sept. .	46,409	48,775	1,568·90	29·58	31·10
Friday, 29 Sept. .	44,492	46,975	1,536·06	28·97	30·58
Saturday, 30 Sept. .	40,400	43,055	1,441·07	28·04	29·88
Sunday, 1 Oct. . .	10,499	13,905	1·45	7,340·69	9,589·66
Monday, 2 Oct. . .	33,487	36,415	1,008·90	33·19	36·09
Summary and Average	175,287	189,125	5,556·38	31·55	34·04

to a compound non-condensing winder on the Continent. The stroke was 1,800 millimetres and the diameters 950 and 1,300 millimetres; the distance between boilers and engine was 20 metres, the steam-pressure 6½ atmospheres, depth 328 metres, quantity of coal 1,100 tons in two shifts. This Table was very instructive, as it covered a characteristic part of the week. Thursday and Friday were full shifts, while on Saturday work was somewhat curtailed. On Sunday probably only one journey was made, and on Monday the conditions seemed to have been fairly similar to those obtaining in England; the manager had evidently not succeeded in getting the

colliery into full swing. The figures showed that the losses in the pipes increased, as could only be expected, with the decrease of useful work; but the losses in the other parts of the installation were far worse, and the last column showed clearly that under the prevailing system of steam-winders, the colliery had to pay heavily when, through some circumstance or other, it could not get the full output, and had to pay excessively when the winding-plant was only required for casual work. He thought that a properly-conducted electric-supply business, which had all kinds of consumers, including railways, could easily prepare to meet demands of the nature described, so that these losses could be avoided. Although it might be difficult to find out at the present moment who paid for these losses—whether the coal-owner, the miner, or the ratepayer—certainly someone had to bear them, and it would be a national saving if they could be avoided. Dr. Herzfeld.

Mr. E. R. Dolby thought it would add to the interest of Mr. Kellow's Paper if the Author would say whether there was one nozzle only or several, and would show the relative position of nozzle (or nozzles) and wheel-buckets which he considered most suitable for the purpose. Mr. Dolby.

Mr. W. H. Patchell was interested in Mr. Preece's reference to the Home Office rules, because he had had the honour of serving on the Committee which drew them up. The Committee's report was issued in 1904; it was considerably modified at the instance of the different associations interested, and in 1905 the rules were issued by the Home Office as special rules. Recently, before the Royal Commission on Mines, one of the senior inspectors had stated that he thought the rules were too long, and that a dozen rules might have covered all the chief sources of danger. Mr. Patchell hoped that, as a result of the 2 years' working of the special rules, an opportunity would soon be given to revise them: one rule, "Thou shalt do good work," would be enough, if it were faithfully observed. The special rules were under Section 51 of the Act, and every person offending against them committed an offence under the Act, so that colliery-managers and others responsible for collieries did not care to have all the extra rules hanging over their heads, which was a serious matter for them. The bulk of what he might call the semi-technical part of the Paper had been much discussed in the Press during the last 3 or 4 years. The German mines mentioned had been visited by many, so that they were fairly familiar. It was, in his opinion, almost a pity to discuss the question of winders until more facts with regard to them were obtained. Those just given by Dr. Herzfeld were very much to Mr. Patchell.

Mr. Patchell. the point. Mr. Preece referred to one winder which was being made for South Wales. Mr. Patchell had a larger one in hand; but until some electrical winders were actually at work in England there would naturally be a dearth of information, and he thought it was a pity to discuss in the meantime the same data over and over again. In regard to one point in Mr. Preece's Paper he wondered whether "coming events cast their shadows before." The figures given on p. 89 referred to the area which it had been proposed should be supplied by the London County Council under its Bill of 1906; and Mr. Preece stated that the prices given would have to be modified, and that the net cost to a mine for transformed current would be slightly higher. Were the Kent Collieries likely to come within the area of the London County Council?

Mr. Jones. Mr. T. Jones thought it might be useful to the members to have some information as to the method of working slate-mines, as Mr. Kellow's Paper dealt more especially with the adaptation of hydro-electric power to their working. The slate-workings of Merionethshire were practically all mines, very few being worked in the open. The strata dipped at various angles, and as soon as the workings became too deep to be carried on in the open at a profit, this method had to be replaced by working in underground chambers, descending in steps 50 to 60 feet in depth from floor to floor, with levels passing through intervening walls of slate rock left to support the mountain. The very large percentage of slate rock that had to be thrown to waste in many quarries rendered it a matter of great importance that every possible fraction of a penny should be saved in dealing with the product. In some quarries the ratio of the yield of manufactured slate to the amount thrown over the tips and drawn up from underground was anything between 1 in 20 and 1 in 25: that was, 19 to 24 tons were thrown over the tip for 1 ton that was utilized. In fairly good quarries that ratio improved up to as much as 9 to 1 or 7 to 1. In the bulk of the quarries (where a primary power of some description has to be used) one of the most serious sources of expense had been the cost of steam-power. Mr. Kellow's installation, he believed, had been actually the first to use in the slate districts, on any large scale, water-generated power through the medium of electricity; although a much larger one had since been established in North Wales at Cwm Dyli on the side of Snowdon. By cutting away a portion of the lip of the bucket of his Pelton wheel and cutting the mouth of the pipe-nozzle at an angle, Mr. Kellow had been able to bring the nozzle well into the lip of the bucket. Mr. Jones had not seen before any appliance that would bring water so closely on to the plane of the impulse wheel as was shown in the

Paper. The point he could not make out, however, was how it was arranged that there was not waste of power through the forward buckets that were disappearing round the periphery of the wheel as the buckets behind received the full impact of the jet. He understood Mr. Kellow had so placed the nozzle, and had fixed the buckets on the wheel at such an angle, that the loss by the old form of Pelton bucket was avoided. The relative efficiency of the two forms of buckets clearly showed that these alterations gave a higher efficiency than the old Pelton form. He thought that Mr. Kellow's experiments had been very well directed, and the results would be of benefit to water-power engineers in the future. The air-chamber at the bottom of the pipe-line was very ingenious, and had since been adopted in another application of electric power to slate-mining in the Festiniog district. He hoped Mr. Kellow would furnish the data he possessed as to the cost of steam (which he had had in use in his quarry up to within the last 2 years) as compared with electricity generated by water-power. These figures would, Mr. Jones believed, show a difference so large as to justify all who were engaged in industries of that description, wherever there was a large rainfall and conveniences for storage, in believing that hydro-electric power had now become a very important factor in the success of industries like slate-quarrying. There were certain distinct advantages in electrical winding up inclines. The inclines in the slate-quarries were at angles ranging from 15° to 45°, and the loads varied very much. The blocks were sometimes 25 feet long, and sometimes 4 feet long, the width was from 2 to 5 feet, and the weight ranged from 1½ ton to 3½ or 4 tons. It was therefore essential to have steady winding up the underground inclines, and the initial torque was an important factor. The load should not be gripped too violently at starting, or the sled on which the block was placed would be shaken and would lose the rough centre of gravity which the quarryman had given to it in the loading. The waste material was very loose and shaly, and therefore could not be well packed in the rubbish wagons. The loose rubbish weighed 1½ to 1¾ ton per wagon-load, and it was made up of different-sized pieces. It was not like coal, which could be dealt with in a tub. Some of the thin waste slabs were put behind in the wagons and round the sides, and the loose material was shovelled on the top and kept in by the slabs. Since the adoption of electricity for winding, accidents and derailments on the inclines had been much less frequent than with steam-winding. Once the load was on the rope, there was very steady winding to the top of the incline. The inclines had several

Mr. Jones.

Mr. Jones. landings, and the loads had to be taken from different floors, where there were the necessary crossings or points. These crossings were fruitful sources of derailment; but with electrical winding the loads could be carried over the crossings much better than with steam. Where steam had to be used in underground work it had been found very detrimental. Although there were large openings in the mountain-side, the ventilation was difficult, and the steam and the sulphurous fumes hung about the workings very much. While no gases arose in the workings, such as were found in collieries, the fumes from the boilers were so bad that in some cases, when the wind had been contrary, he was sorry to say men had been actually suffocated. By the use of electricity, the underground atmosphere had been freed from these fumes, and that was another great advantage in the application of electricity to slate-mining. With steam, the loss by condensation was serious, coal being very costly. In no quarries in North Wales that he was acquainted with did coal cost less at the engines than 14*s*. to 15*s*. per ton, and South Wales coal cost about 23*s*. per ton. For a long time attention had been directed to obtain a cheaper power for working slate-mines. There were some drawbacks in connection with water-power in those mountainous districts. In the winter there were hard frosts, and the channels might be stopped by snow; but as most of the collecting-districts in North Wales were near the sea-shore, and consequently close to the Gulf Stream influence, the frosts were not so long and hard as those in America and elsewhere, and therefore such deterrent considerations were not so prominent in Wales as they would be in inland places. There were other difficulties also. It was necessary to duplicate the machinery to a large extent, and to have spare machines, because the mines were far away from any repairing-centres. If anything broke down that the smiths were unable to deal with on the spot, there was great loss of time in carrying out the necessary repairs. Mr. Kellow said that his mills were lighted by glow-lamps. In North Wales, Mr. Jones was sorry to say, none of the workmen would work after dark; their hours were 7 a.m. to 5.30 p.m. in summer, and 8 to 4 in winter. Therefore lighting in the mills was a subsidiary matter, but electric light was valuable in the mine at large collecting-places, and at the head and foot of the underground inclines. Another point was, that electric power was valuable for the lifting-winches in the mine sinks. When sinking, there were no regular inclines and small winches were used; hitherto those winches had been worked either by hand or by compressed air, but Mr. Kellow had ingeniously adapted to the winches an electric

motor, which did excellent work. He would like to ask why Mr. Kellow took 40·7 per cent. of the theoretical velocity for the peripheral speed of his wheel—upon what basis he founded that percentage. Also, whether he attributed the improvement in efficiency to cutting out the lip of the bucket, or to cutting off diagonally part of the mouth of the pipe-nozzle and so getting the nozzle closer into the working-faces of the buckets. Mr. Kellow did not give the diameter of the feeding-pipes, nor the gradient at which they came on to the impulse-wheel, but by calculation Mr. Jones made the theoretical power at the reservoir about 450 HP. and the effective power, as stated at the end of the Paper, was 64·43 per cent.; in other words, the effective power was 290 B.HP. He ventured to say that that was an exceptional result. With the electrical features of the Paper he did not feel himself qualified to deal. Single driving had to be used on inclines, but group driving for the mills was no doubt a valuable means of equalizing the load on the motors. The great point in grouping was that it was possible to stop a group of sawing-tables and dressing-machines without stopping the whole mill. Some of the mills had more than thirty sawing-tables 9 to 11 feet long, and the necessary dressing-tables for the slate; and it would be a serious matter to stop them all at one time. An important point was that the motors in the mills were capable of local control by the men working each group of four or six tables; they could shut them off if there was any slipping of the belting, or any accident of that kind. Electricity seemed to him also a very useful power for pumping. The centrifugal pumps that had been put in were very efficient. In the Oakeley quarries there were pumps pumping 1,600 gallons per minute, and a new two-stage centrifugal pump was now being driven by a 150-HP. motor, which lifted 800 gallons per minute through 220 feet. Papers read recently before the Midland Institute of Mining Engineers by Mr. Percy C. Greaves[1] and Mr. A. J. Tonge,[2] and the discussion thereon, afforded a good deal of information as to the cost of power at various collieries; and, having thought that it would be interesting to show what it cost with coal at a very low price, for comparison with what it was costing Mr. Kellow[3] at his own quarry with water, Mr. Jones had prepared a Table (p. 110), which he would hand in. The cheapest steam-generated electric power given

Mr. Jones.

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[1] "Cost of an Electrical Unit at a Colliery." Transactions of the Institution of Mining Engineers, vol. xxxii, p. 363.

[2] "A Colliery-Plant: its Economy and Waste." *Ibid.*, vol. xxix, p. 153.

[3] *Post*, p. 123.

Mr. Jones. was by Mr. Gill, of Normanton, from 5 years' running. Mr. Gill put his actual working-cost at 0·26*d.* per unit, taking coal at 3*s.* 5*d.* per ton, and, including capital charges, the whole cost was only 0·49*d.* per unit.

Mr. Bailey. Mr. T. H. BAILEY was more interested in the Paper by Mr. Preece, to whom he thought The Institution was indebted for bringing before it so clearly and fully the subject of electric winding. He was not prepared to go into the electrical part of the question, but wished to mention a few points with regard to the usefulness or otherwise of electric winding. In 1891 it was his privilege to put in what he believed to be the first electrical installation for haulage underground. The great difficulty underground, especially in mines which gave off much gas, was the sparking at the motors and the switches, and also the danger of anything dropping from the roof and interfering with the cables and causing a breakage. The colliery was the Plymouth Works in South Wales,

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The following is the Table referred to on p. 109.—SEC. INST. C.E.

COST OF STEAM AND ELECTRIC POWER.

P. C. Greaves	Weekly cost £15 6*s.* 3*d.*, including capital charges	0·83*d.* per B.T.U.
	Weekly cost £9 8*s.* 5*d.* with coal at 3*s.* 6*d.* per ton, excluding capital charges	0·51*d.* „ „
A. J. Tonge	Silesian colliery on a 10-hour day	Steam, 0·5*d.* Electric, 0·33*d.* B.HP.-hour
J. F. Lee	Three-phase plant. Coal 4*s.* 0*d.* per ton	0·365*d.* per B.HP.-hour.
M. H. Habershon	Coal 6*s.* 8*d.* per ton. Steam generation	0·418*d.* „ „ „
	Anthracite 25*s.* per ton. Suction gas generation	0·350*d.* „ „ „
	3,000 hours per annum.	
	A company in Westphalia paid ⅝*d.* per unit and collected it from collieries.	
Isaac Hodges	Whitwood Collieries. Haigh-moor, smudge 3*s.* 6*d.* per ton.	
	Allowing interest at 4% „ depreciation at 5% steam-power	0·31*d.* per B.HP.-hour.
R. Holiday	Cost, including repairs, etc.	0·75*d.* per B.T.U.
J. Gill	Normanton. Coal at 3*s.* 5*d.* per ton	
	From 5 years' running, actual working-cost	0·26*d.* per „
	Or, including capital charges	0·49*d.* „ „
W. B. Shaw	Hulton. Int. at 5% Depreciation at 10% coal at 5*s.* 6*d.* per ton	0·568*d* in 1904 per B.T.U. 0·579*d.* „ 1905 „ „ 0·425*d.* „ 1906 „ „

and the installation was put down by Colonel Crompton, one of the pioneers of electrical work. It worked a main and tail rope about 800 yards from the pit-bottom, and after the installation had been put in it was found the output was doubled and the colliery was relieved of about fifty horses. He had had no experience of putting in electric winders, but 2 years ago, when his firm were thinking of changing a pair of winding-engines at the Littleton Collieries, near Cannock, he went into the question of electric winding, and found that the cost of it, with the generators and the whole apparatus, would be four times as much as putting down the simple winding-engine. That put the electrical installation out of court altogether, because colliery-owners could not afford to spend such an amount of capital in putting down electric plant. Steam-engines were admitted to be simple, reliable, and cheap in erection, and the cost of maintenance was low, thus meeting all the requirements of their work. As mentioned in the Paper, extravagance in working was the drawback, owing to the short runs and the short time of working at full load. Anyone who looked at *Fig. 1* of Mr. Preece's Paper must be struck with the extremely short time during which the power of the plant was fully occupied. Therefore many things had to be considered before it was possible to get a really useful effect out of the machinery. When the steam-engine stopped, the cost stopped to a large extent, but with an electrical installation the generating-plant had to be kept running, with all the losses it entailed when the power was not being used. On p. 79 some particulars of the depth, load, etc., were given, and he had compared them with the corresponding figures of the plant put down at the Littleton Colliery, which consisted of a pair of 36-inch winding-engines, working at 120 lbs. per square inch steam-pressure. The drum was 18 feet in diameter, the depth was 550 yards, the weight of the load was 25,000 lbs. instead of 8,000, and the weight of the rope 5,000 lbs., while the time of the trip was 50 seconds, and 20 seconds were taken for landing. With six tubs on a cage, three on a deck, the plant would wind about 180 to 200 tons an hour. In Appendix II was described a German winding-gear driven by a three-phase alternating-current motor, and it was said that the plant was designed to wind 100 tons of coal per hour from a depth of 765 yards, that a Koepe pulley was used, and that the weight of coal in each load moved was 2·4 tons as against nearly 4 tons in the case he had mentioned. The four tubs weighed 1·8 ton, the cage 3·16 tons, and the rope 4·18 tons; and the output for the whole plant, which must have cost a

Mr. Bailey.

Mr Bailey. large sum of money, was 100 tons of coal per hour. He did not think any English engineer would be satisfied with that result after such an expenditure. If the motors and dynamos were large enough to deal with the useful load, he was quite sure, from what he had seen of the work of hauling, that trouble and breakdowns must be expected, especially if the landing had to be done not simultaneously but each deck separately. A great strain was thrown upon the engines in having to lift the one cage when the balance was off the other cage. When one cage was being landed, the other cage must naturally be on the sills or supports. In steam-winders, the power of one cylinder had to be equal to the starting-load, because there a difficulty always arose from the position of the cranks, owing to the stretching of the rope. With a rope of any length it was not possible to keep the cages exactly in the same position. The Koepe pulley could be used only when single-deck cages were employed, or when there was simultaneous removal of the tubs from all the decks: otherwise difficulties arose from the unbalanced load. Mr. Preece mentioned tapered ropes. Mr. Bailey had had some experience of them, and he did not like them; they could not be relied upon, and it would be next to impossible to arrange for the windings not to coincide, as suggested in the Paper, when there were two plants entirely dependent on the men who had to push the coal on at the bottom and take it off at the top, the winders at the same time being controlled by other men. The two engines would seldom be working strictly alternately. He had no doubt that the three-phase system would be the most suitable, provided the serious difficulty of starting with an overload could be surmounted. *Fig. 1* showed that full load lasted only a short time, and that there were long intervals with very little load, during which time there must be loss due to the friction of the heavy fly-wheels, the dynamos, and the motors, and also in the power required to keep up the momentum of all the moving parts. Where shunt-wound dynamos and motors were separately excited, that meant a constant power, regardless of the load upon the winding-plant, for exciting purposes only, and a further loss due to the friction of all the moving parts, a fact which seemed to have been overlooked in the Paper. With regard to batteries, he had had some experience with electrical welding, where the energy was derived from water-power. In one case a battery had been put down to take up the current when the welding was not being done, and it had been found that the sudden taking of the current from the batteries was ruinous to them. He did not think

they would be of any avail for electrical winding. The Author had dealt only with electrical energy spent in the actual winding. Certain losses must of necessity take place, losses which were not mentioned in the Paper. First of all, there was the loss in the steam-engine or the gas-engine used for generating the power when working at full load or when running light; there were the losses in the dynamo, in the cable, in the motor-dynamo, in the cables between the dynamo-motor and the winding-motor, in the regulating-resistances, and in the separate generating-plant for exciting purposes. Most of these losses were continuous, whereas in steam winding-engines the losses only occurred whilst actually working. What he felt about the whole question of the electrical winding was that, where steam could be used direct from the boilers without difficulty, the steam-engine was the most economical and satisfactory winding-machine. He was doubtful whether, as far as England was concerned, electric winding would ever come to the front. Where the power had to be carried a long way underground or down shafts, the advantages of the electric current were manifest, but not where it was possible to erect the boilers at the pit-top and to take the steam direct for the work. It seemed to him folly to put down a steam-plant in order to generate electric current for driving an engine close at hand. Mr. Bailey.

Mr. Charles P. Sparks had had some opportunity of considering the different attitude assumed towards electric winding on the Continent and in England, to which Mr. Preece alluded in his Paper, and he had found substantial reasons for the difference in practice. In the first place, the question was wholly wrapped up in the fact of the high capital cost of the electric winding-plant. There was a substantial gain so far as the working-costs went, owing to the very heavy stand-by losses on steam-plant and the relatively high steam-consumption of winding-engines as compared with electrical power. In regard to that question of cost, there were first of all interest and depreciation, and, secondly, running-costs. On the Continent the hours of working were different from those in England; instead of a day of 9 to 10 hours they had a day of 16 hours and upwards, and consequently the interest-charges were relatively of less importance on the Continent, while, on the other hand the running-charges, for the longer time, were of considerably more importance. Next, the cost of fuel was higher on the Continent, and therefore economy in the running-cost was of great importance. Lastly, in no case was electrical winding Mr. Sparks.

Mr. Sparks. treated as a separate matter; it was a question of general power-application of electricity to a mine, of which winding formed a part, and therefore it was not steam-winding versus electrical winding, but steam-power versus electrical power. In the case he had considered, the collieries had been in no way deterred by risk of its being experimental, or on account of difficulty in raising the necessary capital; but they had found, even allowing an economy of about 30 per cent. in running-costs, that the capital charges were such that electric winding would have put them at a substantial disadvantage. As soon as the capital charges fell—and he thought there was every hope, with improvements, of seeing a large reduction in the cost of electric winding-plant—there was no doubt that there would be a fair field for main winding in England. With regard to subsidiary winding, such as the use of winders for men and stores, he had had experience of four small applications where the motors were of 100 to 250 HP., and there had been a very substantial saving, owing to the fact that it was possible to shut down the boilers at isolated parts of the colliery, maintaining the steam-plant at one point. On p. 79 Mr. Preece alluded to the question of having two speeds, one for winding coal and the other for winding men, but that appeared to have been written under a misapprehension. It was true that on the Continent winding was practised with two speeds, but in England the modification of speed, if any, was small. Another question intimately connected with the subject of winding was the fact that there were so many points at which electric power in collieries showed relatively a much larger saving. For instance, in English collieries the haulage systems were exceedingly large, in many cases requiring thousands of horse-power. In colliery-practice abroad there was scarcely any haulage comparable with the haulage in this country. Steam-haulage was cheaper than horse-haulage, but electrical haulage was so much more convenient, and the saving was so substantial, that it paid every colliery to turn its attention to electrical haulage underground before dealing with the question of main winding, which was carried out reliably and efficiently in his opinion by steam at the present time. The second part of the Paper dealt with the question of the cost of electric power, and on p. 89 a Table was given. He was familiar with tables of that nature, but did not recognize that particular one. The lowest terms he had seen for power delivered at a pressure suitable for use were quite 20 per cent. higher than the figures given in the Author's Table, and in that case they were not for power

delivered in scattered colliery-districts, but in a much denser district. Mr. Sparks.
The addition of 20 per cent. to the figures made a very substantial difference. With a 20 per cent. load-factor the cost would be 0·85*d*., with a 33 per cent. load-factor, 0·61*d*., and with a 50 per cent. load-factor, 0·49*d*., or roughly a halfpenny. His experience of colliery-work showed that in an electrical installation of about 6,000 HP., a load-factor in the vicinity of 40 per cent. could be expected, so that the cost of an outside supply might be put at about a halfpenny per unit. In another part of the Paper comparison was drawn between the use of steam- and gas-engines, and it was suggested that the gas-engine should be worked by producer-gas. In his own opinion there was no scope for the application of producer-gas in colliery-districts. The power had either to be obtained from steam or from gas obtained from coke-ovens or blast-furnaces. His name was mentioned in the Paper in connection with a company which at present was putting down gas-engines. They had one gas-engine at work developing 1,200 B.HP. with twin cylinders, and a second engine of 2,400 B.HP. was being built. He was not able to give actual results with regard to the cost of working over a period, because the first engine had been at work only about 2 months; but he might point out that the possible saving through the use of gas-engines was small. To illustrate this, without giving exact figures, he might take the cost of fuel per unit as being something like 0·1*d*. in the colliery-district. By using the gases directly in gas-engines instead of burning them under boilers, the maximum economy was of the order of 0·06*d*. per unit, and out of that had to be paid the extra interest, depreciation, and repairs. Interest and depreciation was a heavy item, in the first place because the engines had little overload-capacity. In considering the cost of plant it was not possible to compare the rated capacity; it was necessary to consider, especially in colliery-work, the importance of the overload-capacity. The figures on p. 91, with the cost per kilowatt taken at £10 and at £20, showed the relative value of different load-factors. Without taking those particular figures for steam and gas as being in the ratio of 10 to 20, but assuming they were so for the moment, in order to get the saving of 0·06*d*. it was necessary to have a 75 per cent. load-factor, when, if the cost was in that proportion, there would be a saving of 0·06*d*. In the particular case he had referred to, the capital expenditure was not quite in the ratio of 2 to 1; but unless there was a load-factor exceeding 50 per cent. there would be no saving at all in using a gas-engine as compared with using the gases under boilers. The real reason

Mr. Sparks. the company in question had gone in for gas-engines was that they had an exceptional opportunity in that particular colliery-district, and were able to secure a load-factor of about 70 per cent. The saving through using the gas, after taking interest and depreciation into consideration, was probably about 0·025*d.* per unit generated, so that the actual gain per unit was very small, although it became of importance on millions of units. His name was also mentioned in another part of the Paper in connection with the cost of electric power, and he could now give the cost of a complete year in connection with the colliery in question. The output for the complete 12 months was 4,800,000 units. The average power during the year was 4,500 HP., the normal capacity of the steam-driven generators was 3,000 kilowatts, the average cost of coal during the year was 5*s.* per ton, the consumption of coal per unit delivered to the mains was 3·7 lbs., and in the result the interest- and depreciation-charges, taken at 10 per cent., were 0·17*d.*, the working-costs 0·18*d.*, and the total cost of the supply 0·35*d.*, per unit. That was a slight improvement on the figures he had indicated for the period of working when reading a Paper before another Institution.[1] With the improvement in the load-factor which would result from gradual increase of business, and especially through the introduction of pumping, the cost would be reduced to slightly under 0·3*d.* Mr. Preece drew a comparison between supply by a power-company and a colliery supplying itself, and indicated that with a load-factor of 20 per cent. the colliery would probably purchase power from a power-company, whereas, with a load-factor of 50 per cent., it would supply itself. In view of what he had already said, he thought that in all probability the colliery-company would supply itself even if its load-factor were as low as 20 per cent.; but he saw no reason to anticipate the 20 per cent. load factor unless it was some very exceptional colliery. Therefore, for all medium-sized collieries, he took it the question of supply was simply a question whether the colliery had a sufficiently long life to justify the owners in spending a certain sum of money. If it had, they would supply themselves with power; but the owners of a colliery with only a short life would take the supply from a power-company.

Mr. Steiger. Mr. A. Steiger observed that when a Pelton wheel gave a higher efficiency than 80 per cent. he was inclined to doubt the correctness of the tests, even though improvements had been intro-

[1] Transactions of the Institution of Electrical Engineers, vol. 36, p. 497.

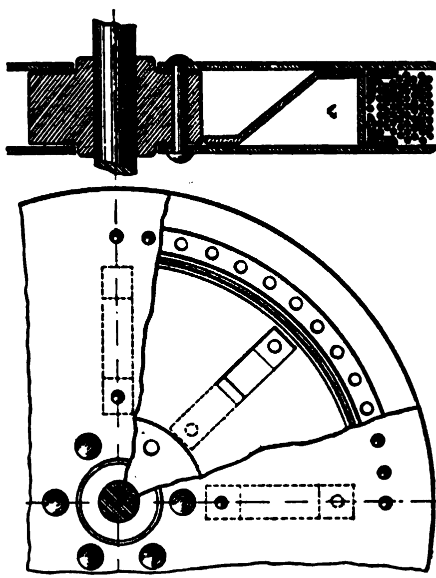
duced by bringing the nozzle close to the buckets and by adopting what seemed a better form of bucket. What made him doubt the efficiency as given in Mr. Kellow's curves was the peripheral speed-ratio of 40·7 per cent., because in impulse turbines it was taken generally that the maximum efficiency was obtained when the peripheral speed was 50 per cent. of the velocity of the water due to the head. If the peripheral velocity was less than the relative velocity with which the water passed through the buckets—which was constant—then of course the absolute velocity of the water leaving the buckets, which represented a loss, was also greater. He therefore wished to have some explanation as to how those tests had been made. It was rather interesting in the curves to note the great drop in efficiency with a change from 50 per cent. volume to 25 per cent. volume, which, in his opinion, had to do with the nozzle. If a spear was inserted to such an extent that only about one-quarter of the full volume of the water was discharged, a very thin stream was obtained, and the water had to impinge on the buckets in an improper way: in that respect he thought the rectangular nozzles were decidedly better, although much depended on how rectangular nozzles were placed. In a case where he had had to test a Pelton wheel which gave very unsatisfactory results, the nozzle was much too large and was almost square. The available volume of water being too small, the nozzle was shut to about 1½ inch, with a length of 6 inches, so that the water entered the buckets in a thin stream, and that was one of the many causes of the bad results. He suggested making an alteration in the buckets and in the nozzle, and that, instead of having a rectangular nozzle placed with the long side perpendicular to the direction of rotation the long side should be put in the same plane as the direction of rotation, and the efficiency then became very satisfactory considering that a good job had to be made out of a bad one. He could not remove the wheel, as this would have meant complete reconstruction of the whole plant. A glance at the two different types of buckets shown in *Figs.* 6 and 7 would show that *Figs.* 7 was a great improvement on *Figs.* 6, but a bucket as shown in *Figs.* 6 could not be equally efficient with that shown in *Figs.* 7. A great deal depended on the design. With respect to *Figs.* 6, the nozzle could be brought equally near, so that so far the efficiency of the bucket in *Figs.* 6 could have been made as good as that of *Figs.* 7. Each maker of turbines had his own idea about the shape of buckets, and any careful designer of turbines would certainly design a bucket of the "A" type different from that shown in *Figs.* 6, to make it as efficient as that shown in *Figs.* 7. Mr. Steiger.

Mr. Hanssen. Mr. C. T. A. Hanssen had also been very much struck with the wonderfully high efficiencies obtained by Mr. Kellow, and would be glad of a few particulars with regard to the conduct of the trials. It seemed from the Paper that the frictional resistance of the pipe was included in the very high efficiencies, and it would be interesting to know whether that was so—whether it was really possible to get an efficiency of nearly 88 per cent. with a Pelton wheel of that type. He had had an opportunity of inspecting a very similar installation in Switzerland, near Vevey, where there was a fall, from Lake Tanay to the River Rhone, of nearly 3,000 feet, the whole of which was utilized on very similar lines, though there were several points of difference. One was that the jet-opening was rectangular, and instead of a single jet-opening there were two jets playing on the wheels, something like the De Laval steam-turbine, where a number of jets played on the wheels at various points. The governor was highly ingenious and governed the wheel very effectually, but only one of the jets was under its control, the other always spouting full bore. The jet which was governed had a small slide-valve at its outlet which fitted very exactly, and the longitudinal rectangular slit was gradually closed as required. The engineer responsible for the works, Mr. Boucher, had very kindly given all the information at his disposal. Lap-welded pipes were used, and the joint was an ordinary socketed butt joint. A loose flange ring was slipped over each pipe, and the two rings, bearing against collars welded on the ends of the pipes, were held together by strong bolts. The pipes had to follow the contour of the ground, and the angle was adjusted—which with flanged pipes was generally a difficult matter—by using two wedge-shaped rings between the joints; by turning the rings the two thick parts or the two thin parts could coincide, or be intermediate between, and in that way the pipes could be adjusted to any angle between 0° and 10°, and could follow almost any declivity of the surface, thus enabling them to be well buried in the ground. Altogether the installation was extremely well thought out, and ample provision was made for preventing any water-hammer action in the pipes. Mr. Boucher only claimed 75 per cent. efficiency, excluding the friction in the pipe itself, and he seemed to consider that very good. The pipes were about 12 inches in diameter, and 2,000 yards long, so that the friction in them with a velocity of upwards of 9 feet per second was considerable. In Mr. Kellow's case the pipes might have been larger in diameter, or the form of the jet might have been a really important improvement.

Mr. Druitt Halpin, speaking on Mr. Preece's Paper, quite agreed that, where it was a question of transmitting power, electricity might be usefully employed in collieries, whether in haulage, ventilation, or pumping; but he failed to see where it could come in satisfactorily for winding. It was almost a similar case, in his mind, to that of the locomotive in which the most direct action was obtained; the steam turned a crank-pin which turned a wheel, and there was an end of it. Direct winding was a precisely similar process, and was free from the heavy losses in transmission which must naturally result from the interposition of the machinery and cables between the engine and the load to be dealt with. On p. 98 the Author gave the efficiency in one case as 51 per cent. It was an exceedingly small installation, but any figure of that nature Mr. Halpin looked upon as of a very small value, and apparently it did not take in the electrical losses reckoned from the engine right through the general transmissions. The argument with regard to the advantage of winding electrically was, as far as he could understand it, that with steam winding there was more stress on the ropes, that was, that the velocity of the periphery of the drum was less constant than with electrical winding, and that consequently the winding might be done at higher speed and with more safety if electricity were employed. If greater uniformity was required in the travel of the rope—in the velocity of the circumference of the drum—it might be more easily and cheaply got by the introduction of a third cylinder in order to get a more even torque. If Mr. Preece made a strong point of the regularity of the winding-velocity, he would add to the value of his Paper by giving some graphical information showing what he alleged to take place to a detrimental extent. Mr. Halpin believed the President had exhibited diagrams of that nature made on smoked glass some years ago, and Mr. Ransom had done the same. Such diagrams would be worth having, as showing what was to be saved by the application of so much inefficient and apparently very costly machinery. Some of the large fly-wheels referred to in the Paper were described as being made of cast steel for the sake of safety. Quite apart from excessive speeds of such wheels, very disastrous accidents had happened in rolling-mills to engines which were under control and rolling plates; and they were easily explained when it was borne in mind how the wheels were often fitted together with all kinds of fish-joints, quite out of proportion to the stresses put upon them. Such built-up wheels were expensive to erect, costly in carriage, and generally difficult to deal with. About 20 years ago, to get over the Mr. Halpin.

Mr. Halpin. trouble of carriage and want of safety, he designed the wheel illustrated in a diagram which he had put on the wall (*Figs. 1*). The centre of the wheel was of cast iron and the wheel was built up of plates which formed a trough at the rim. The necessary weight was then obtained by inserting in the trough, in tension, hard wire of 70 or 80 tons per square inch tensile strength. The wheel was therefore very easily erected. The cost of carriage and the difficulty of erection were reduced to a minimum.

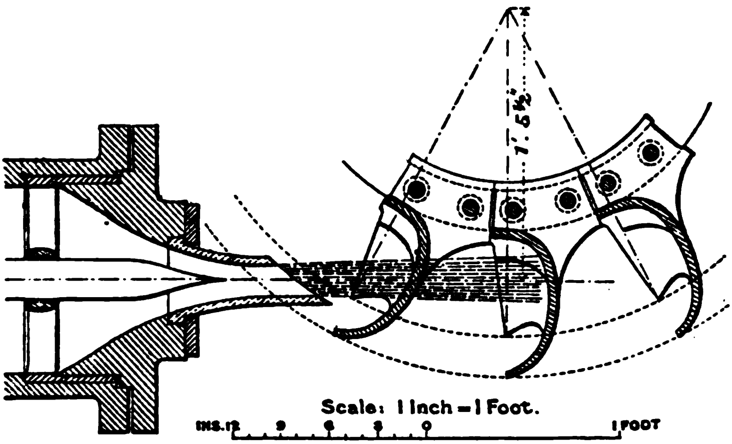
Figs. 1.



Mr. Kellow. Mr. KELLOW, in reply, stated that the turbine had only one nozzle, and its position relatively to the buckets could be seen from *Fig. 2*, which showed nozzle and buckets in section. *Fig. 3* was a plan which indicated the line on which the section of the bucket shown in *Fig. 2* was taken. The height of the nozzle relatively to the buckets was a point of considerable importance, as with open lips care had to be taken that water did not escape through them as they ascended from their lowest position. In the size of wheel shown in *Fig. 2* the axis of the jet intersected the dividing wedge

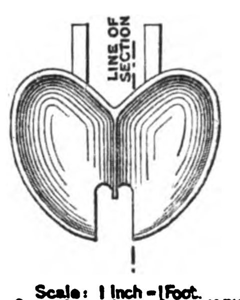
of the bucket at three-fourths of its length inwards, when the latter was in a vertical position. Peripheral speeds had been calculated Mr. Kellow

Fig. 2.



at this point of intersection, which corresponded with a circumference to which the jet was tangential; and 40·7 per cent. of the theoretical velocity of the water had been adopted as the peripheral speed of the wheel, because the experiments had shown that that was the speed of highest efficiency at the load the wheel would ordinarily be required to deal with. Though he had been somewhat surprised to find from the experiments that the divergence from the text-book figure of 50 per cent. was so considerable, he thought that several reasons could be brought forward to support the adoption of a much lower figure than 50 per cent. In order to justify the text-book figure it was necessary to postulate three propositions: (1) That no retardation of the relative velocity of the water took place during its passage through the nozzle and over the surfaces of the buckets. (2) That the flow was axial. (3) That the highest efficiency was obtained when the water left the buckets with no residual velocity (relatively to the earth). None of these propositions could be substantiated. The friction

Fig. 3.



Mr. Kellow. of the water at the high velocities at which it issued from the nozzle and flowed over the buckets of an impulse wheel was too important to be neglected, and its effect would be to reduce the velocity. The flow in an impulse turbine like the Pelton wheel was only momentarily axial, by reason of the direction of motion of the buckets deviating from the rectilinear; and in the case of a turbine having buckets and a nozzle of the forms, and occupying the relative positions, shown in *Fig. 2*, there was an inward component in the mean direction of flow, which involved a retardation of water by centrifugal force due to the rotation of the wheel. A certain amount of residual velocity facilitated the clearance of the discharged water, and prevented it from striking the following bucket. The discharge of the water with 10 per cent. of its original velocity only represented a loss of 1 per cent. of the total energy. The general conclusions were that at the lower peripheral speed adopted by him the residual velocity was really less than it appeared to be at first sight, that the energy in the discharged water was inconsiderable, and that it was, moreover, usefully employed. He thought there were several reasons why the Pelton bucket, as ordinarily constructed, should give a low efficiency. First, it was usually made too narrow relatively to the width of the jet, so that while the water in the middle might (with the bucket in its best position) be received and deflected by the curved surfaces so as to give up nearly the whole of its energy, that on the outside was directed towards a surface nearly perpendicular to its course, and so acted by impact only, its reactive effects being lost. Secondly, it must be borne in mind that the bucket was not stationary and therefore the ideal conditions, as usually illustrated in makers' catalogues, where the jet was being divided into two streams flowing over semicircular surfaces, was not realized in practice. As a matter of fact, the lip of the bucket first entered the jet, this lip having ordinarily a thick edge which obstructed the smooth flow of the water. Water received on the lip was directed towards the back of the bucket, and in its path it encountered two sharp angles. It also crossed the path of the water deflected by the dividing wedge in the middle of the bucket. Later, after the bucket had passed its mid-position, the direction of flow had an outward component for which the shape of the bucket did not provide. All these defects caused the water to be broken up, and the energy to be lost. He attributed the high efficiency he had obtained to the form of nozzle, the position of the nozzle close to the wheel, the ample size of the bucket, the absence of a lip

on the bucket, the easy curves in the bucket over which the water flowed in its various paths, and the adoption of a lower peripheral speed. The improvements effected in the directions indicated were amply sufficient to account for the difference between the 80 per cent. mentioned by one speaker as obtainable from an ordinary Pelton wheel, and the 87·72 obtainable with the improved construction described in his Paper. The internal diameter of the pipe was 1 foot. The length was 3,200 feet, and the total fall being 861 feet, this represented a mean angle of dip of 15° 36′. The efficiency-curves in *Figs. 9* and *10* did not include pipe-friction; neither did the wheel-efficiency curves in *Fig. 11*. The combined efficiency-curves in *Fig. 11* did include pipe-friction, and the pipe-efficiency was separately shown by a curve in *Fig. 11*. The maximum power developed by the two impulse wheels was 400 HP., but this corresponded with a small overload on the electrical plant. The advantage of electrically lighting the mills had been questioned, but nearly 1½ hour of working-time per day during the dark winter months had been gained by this means. The comparative costs of power by the hydro-electric plant now installed and by the steam plant which preceded it were the following, the basis of comparison being the effective or brake horse-power delivered by the motors in the one case, and the effective or brake horse-power delivered by the steam-engines in the other. Mr. Kellow.

Hydro-Electric System.—The capital outlay for the entire installation divided by the effective horse-power in operation at the mine was £29 8*s*. 3*d*. The reservoir, generating-station, and other parts of the system had been designed with a view to extension in the future, so that it would be unfair to debit the whole of the capital outlay against the instalment already put into operation. A fair proportion to debit against the present instalment would be £20 per effective horse-power. On this basis the cost was

	£	s.	d.
Labour	0	5	0
Oil and sundries	0	2	10
Maintenance at 2 per cent. on capital outlay of £20	0	8	0
Depreciation at 4 per cent.	0	16	0
Interest at 7 per cent.	1	8	0
Total per effective horse-power at the mine per year of 3,000 hours	2	19	10

Steam System.—The capital outlay on boilers, engines, piping, feed-pumps, foundations, buildings, etc., in small units, including carriage to site and fixing, was about £20 per effective or brake

Mr. Kellow. horse-power. Winding being a large feature in slate-mines, and simple non-condensing engines, working intermittently and with a low and variable load-factor, being the predominating element, the consumption of coal was exceedingly high, about 6 lbs. per indicated or 8 lbs. (of South Wales coal) per effective horse-power being the average. Maintenance and depreciation were also heavier than in the case of a hydro-electric system. The cost on this basis was

	£	s.	d.
Coal at 8 lbs. per horse-power-hour for 3,000 hours, 10 tons 14 cwt. at 25s. per ton delivered at the mine	13	7	6
Oil, waste, and sundries	0	7	6
Labour	3	0	0
Maintenance at 3 per cent. on capital outlay of £20	0	12	0
Depreciation at 5 per cent.	1	0	0
Interest at 7 per cent..	1	8	0
Total per effective horse-power at the mine per year of 3,000 hours . .	19	15	0

Per Board-of-Trade unit the figures were

Hydro-electric system	0·321*d.*
Steam system	2·118*d.*

In conclusion, he thanked the members for the kind attention they had given to the Paper, and for the valuable criticisms that had been elicited.

Mr. Preece. Mr. Preece, in reply, thought Mr. Halpin's comparison with the steam-locomotive was hardly suitable. Winding in mine-shafts exactly resembled the class of work upon railways for which locomotives were being rapidly displaced by electric motors. The work was even more onerous than the heaviest suburban traffic, for a winding-gear had to be started rapidly, to run at full speed for a short time, and to be stopped for a few seconds. It had frequently to do this seventy times in an hour, and he thought that electric motors would ultimately prove to be the best for such work. With regard to using a third cylinder in the steam-engine in order to get over the jerky action of the rope, the difficulty with steam-winding was that when the winding-operations started the whole of the work had to be done by the one cylinder, and the addition of any number of cylinders would not get over the severe jerks at the start. The point raised by Mr. Halpin was a very interesting one, but Mr. Preece regretted he had not the means of obtaining graphical information; the impulses set up in steam winding-engines were, however, fully calculated by Mr. Laschinger in the discussion on Mr. Behr's Paper, referred to at p. 77. There was a series of four kicks of varying

Mr. Preece.

intensity, and the drum-inertia could only minimize the effect on the rope as the speed rose. Heavy fly-wheel converters of the Ilgner type were now being largely used, and he had no record of an accident; the fly-wheels were prevented from running away by the motor, which could not exceed a certain speed. The information Mr. Sparks had given would prove very valuable. With reference to the purchase of current by a colliery with a short life, he thought Mr. Sparks had forgotten that the power-companies, in Newcastle at any rate, would not supply large power-users unless they signed agreements to take a minimum supply for at least 10 years, and sometimes he believed the companies held out for 15 years; and therefore a colliery could not pick and choose, but would have to sign or put down its own plant. He quite agreed with the remarks Mr. Sparks had made with regard to gas-engines, and he had not intended to suggest that a colliery should use producer-gas. He had considered the question of winding as applied not so much to collieries as to gold-mines and works of that character. In the case of a gold-mine the fuel question was quite different from what it would be in the case of a colliery. With reference to Mr. Bailey's remarks, the claim made by those who put forward the advantages of electric winding was that, as far as could be ascertained, the steam consumed per effective horse-power in the best type of steam winding-engine was somewhere in the neighbourhood of 100 lbs., whereas with the best type of steam-engine driving dynamos an effective horse-power could be obtained on 25 lbs., speaking roughly, and the difference between 100 lbs. and 25 lbs. was more than sufficient to cover losses that might and did occur in the transformation, first, from steam to electricity, and then from electricity to effective horse-power in winding. Dr. Herzfeld had given some valuable figures showing the very heavy losses in steam-generation during periods of light work in winding, and Mr. Preece thought they emphasized the claims of electric winding. Several speakers had referred to the expense of putting down electric winders, and no doubt if the whole cost of a separate set of engines, dynamos, transmission-plant, etc., were charged to the winding-gear, the cost of a single winding-gear would be enormous; he accepted Mr. Bailey's figure of four times, as being somewhere near the truth. But in a large mine electricity was put to many uses, and the cost of the electrical generating-plant was considerably reduced, with the result that the cost of the electric winding-gear at the pit's mouth need not be higher than the cost of providing steam-engine plant with boilers solely for the purpose of winding. It must be recollected that the boilers and the steam winding-engine must be close to one another, and hence in a mine

Mr. Preece. separate batteries of boilers had to be provided for every shaft and probably for every mill, and in a large mine it frequently happened that there were half-a-dozen batteries of boilers scattered over a large area. If electricity was used for winding, hauling, and for the mills or washers, etc., one large battery of boilers might be used, and the resultant economy in coal and labour alone in the boiler-house would be enormous. The capital expenditure also would be considerably reduced, and Mr. Preece considered that the total capital expenditure, when all isolated plant was electrically driven, would be found to be less than the capital expenditure upon isolated batteries of boilers, steam-engines, and contingent works.

Correspondence.

Mr. Gillott. Mr. THOMAS GILLOTT observed that his experience with electric winding had been confined to a service plant in an upcast staple pit, winding men only, from a depth of about 200 yards; and he had not been encouraged either by this plant, or by the particulars given in Mr. Preece's Paper, to contemplate the general use of electric power for winding at a coal-mine. He wished to ask whether the cages in the three plants referred to in the Appendixes were supported on props at the surface which required the cages to be lifted for withdrawing the props before lowering, or whether the props had to be withdrawn when the cages were resting on them. Props of the latter type were in limited use, but there were objections to them. Also, what arrangements were in use for the carrying out of the daily shaft-examinations usual in English mines? The case given in Appendix III was almost identical with an installation he was concerned with, which had worked about 18 years. The pit was 474 yards deep; four tubs, each containing when full 10 cwt. of coal, were drawn on two decks; and a balance (tail) rope was employed. The pair of engines had 28-inch cylinders, 5 feet stroke, with a 15-foot cylindrical drum on the crank-shaft; the wind from start to stop occupied 48 seconds, and 20 seconds more were required to change. This was much quicker work than at the Wintershall colliery, and the output could not be maintained with a less maximum speed. The speed could easily be maintained throughout the day if the following causes did not operate against it: (1) men absenting themselves from work; (2) irregularity of the rate of out-

put during the course of the day; and (3) services of the winding-engines additional to coal-drawing. The average daily tonnage for a week (February, 1907) was: coal, 590 tons; dirt, 48 tubs (about 30 tons); 367 men requiring thirty-seven double journeys, and extra also for sending down timber and stores; the whole occupying about 9½ hours' winding. The cost of winding-machinery proper for comparison with an electric plant, comprising boilers, seatings, chimney, engine-house, foundations, engines, and pipes, was about £4,200; and the total working-cost, inclusive of interest on and redemption of outlay on this portion of the plant, amounted to £4 5*s.* per working-day. He would be glad if the Author could furnish corresponding information for the Wintershall plant, as the outlay appeared to be enormous for the work that could be done by it. The true "paying load-factor" for the steam-plant described was only about 0·25, and this would probably be considerably reduced by legislative restriction of the working-hours. Again, owing to the exigencies of trade, an average of 250 working-days per annum was all that could be counted on; and as interest and redemption formed about 25 per cent. of the full-time working-cost given, there did not appear to be any chance of an adequate saving in other respects by a costly electrical plant to meet such a charge. Most collieries raised coal that would not bear such a carriage-rate as to find a market for it, and such coal must be used at the colliery or thrown away. Mr. Gillott.

Mr. JOHN HAYES agreed with Mr. Kellow on general grounds, and particularly with his statement that mechanical aids in the manufacture as well as in the mining and quarrying of slate tended to become more universal every year. As to the best means of generating and distributing power in slate-quarries and mines, more particularly in North Wales, there could be no question as to the accuracy of the views put forward by Mr. Kellow where similar natural and topographical advantages prevailed. Unfortunately, however, it would frequently be found, with regard to the slate-mines and quarries of North Wales, that the positions of available water-supplies, on most of these properties, relatively to that of the power-house, and of the latter again to that of the quarry or mine where the electrical energy would be utilized, were either too distant or otherwise inconvenient, and the water could therefore be utilized only at very considerable cost and initial capital outlay. So much was this likely to prove the case, in many instances within Mr. Hayes's knowledge, that the capital outlay necessary would probably be prohibitive. Again, the effects of a prolonged drought could not be ignored, although in the Snowdon Mr. Hayes.

Mr. Hayes. district they might be experienced but seldom. Wherever hydro-electric plants could be installed easily and at moderate cost, the advantages in working were so great that it would be shortsighted policy not to take full advantage of them. But Mr. Hayes was of opinion that, in many instances, if not in most, the balance of advantage, so far as the generation of power at the quarries was concerned, taking all the various factors into account, would be largely on the side of producer-gas plants, rather than with hydro-electric installations. The former possessed the great advantage over the latter that both the generating and the distributing portions of the plant could be placed close to the points where the power was required; whereas with hydraulic plant the water-storage might be some considerable distance from the power-station, and must then be connected by a costly pipe-line; and still more serious from the point of cost was the fact that, in the majority of instances, the transmission-line between power-station and motors must also be a rather expensive item. Mr. Kellow correctly stated that at present, although in some instances water-power was applied, the bulk of the power for working machinery in slate-mines and quarries was being derived from steam. Of late, however, producer-gas had made rapid strides, and was rapidly displacing steam in many of the leading industries, and where new quarries were being opened, or new plants were taking the place of those worn out and otherwise obsolete, most quarry- and mine-owners would not be able in future to shut their eyes to the advantages to be derived from cheap gas-power. Whether the power were derived from a hydro-electric installation, or from gas, the only safe and economical means of distribution about a quarry or mine would always be electrical, and here again the choice of gas-power would tend to determine the rival merits and demerits of the different systems of transmission, as between continuous and alternating current respectively, as well as their initial costs, if indeed it did not go far to prove the great advantages attending the use of the former, and thus dispensing with the use of high voltages and the losses attendant upon the use of transformers, etc. In conclusion, whilst congratulating Mr. Kellow on having contributed so opportune and valuable a Paper, Mr. Hayes somewhat regretted that he had not given also some information as to the actual cost of the plant described, and of its maintenance, as, after all, cost was the main thing to be considered when embarking capital in enterprises of the kind.

Mr. Mountain. Mr. W. C. Mountain held the opinion that for isolated collieries where it was necessary to have steam and the winding required a very large amount of power—probably considerably in excess of the power required for other purposes—there was no commercial

gain in putting in electric winding-machinery. His investigations Mr. Mountain. showed that the consumption of coal per useful horse-power—that was per actual horse-power in the shaft—in lifting the coal, was not very much less with electric winding-machinery than with really high-class steam-winders, whereas the cost of the electric winding-plant, taking into account the proportion which should be allotted to the generating-plant together with the motor-generator and the electrically-driven winding-gear, probably exceeded the cost of a high-class steam winding-gear by two or three times the amount. Therefore, to arrive at any real saving it was necessary to consider:—

(1) The cost of coal per ton.
(2) The amount of coal used by each system.
(3) The probable saving of coal with the electric system.
(4) The amount of wages required by both systems.
(5) The interest and depreciation to be provided for with each plant.

The conclusion to which he had come was that for heavy winding, and under the conditions stated above, the extra amount required for interest and depreciation on the electric-winding scheme would far more than eat up any saving in the coal-consumption. This result of course depended largely on the value of the coal used, and there was no doubt that where coal was expensive the saving would enable electric winding to be adopted; but at most collieries where refuse was used under the boilers which was of practically no value for selling purposes, it was quite clear that very little could be done by saving such material. He was sorry that Mr. Preece had not entered more upon the commercial aspect of electric winding. He quite agreed with him that electric winding was one of the prettiest arrangements that could be put into a pit, and it was also satisfactory in working; but the whole question to his mind was one of cost, and he maintained that the only satisfactory way to determine this point was to omit the steam-consumption per useful horse-power which was harped upon by all electrical engineers, and to prepare at once an estimate of the actual cost of winding coal from the shaft-bottom to the top, including cost of winding per 100 tons, wages, interest, and depreciation, etc., as Mr. Mountain had done,[1] and then it was possible to see at a glance which would pay best.

[1] Journal of the Institution of Electrical Engineers, vol. 36 (1906), p. 499; Transactions of the Institution of Mining Engineers, vol. xxxi (1906), p. 329.

Mr. Thorp. Mr. R. F. THORP gathered from the plan and description of the Croesor hydraulic installation that the service-pipe was laid from the reservoir to the power-house direct. It would appear from the plan that a considerable saving might have been effected by leading the water in an open channel round the hill-side, say on contour-line 1,500, to a point directly above the power-station. He had designed and constructed many water-power installations in India for heads of 150 feet to 750 feet, and had found that this method had invariably led to economy, even when the water-channel had had to be constructed over steep and rocky country. It would be interesting to all engineers who had had to do with hydraulic-power schemes working under high falls if Mr. Kellow would furnish full particulars of the governors used. The governing of hydraulic machines had almost invariably been the greatest difficulty with which the hydraulic engineer had to contend in the design and subsequent working of high-fall installations. Mr. Thorp had had experience with five different types of governors, including those designed by the best Swiss hydraulic engineers, but he had found none of them capable of working up to the maker's specification when more than 15 per cent. to 20 per cent. of the load was thrown off suddenly. He was glad to be able to say that the most satisfactory hydraulic governor he had had to deal with was designed and made in England. It would be interesting to hear Mr. Kellow's experience with the governors used at the Croesor works. Mr. Thorp was surprised to hear that the form of bucket shown in *Figs. 7* (p. 58) gave better results than the usual form of bucket used by most of the best firms of Pelton-wheel makers. He could not help thinking that the bucket shown in *Fig. 6* was not designed on the lines adopted in the best modern practice. This bucket appeared to be too straight on the front lip, and the edges were too thick; the front lip of the bucket should be concave in the centre where it met the bifurcating rib, and in all cases the bucket should not be set radially to the wheel, but be given a backward slope similar to, but somewhat greater than that given to the bucket "B." He thoroughly agreed with Mr. Kellow in his preference for the squirrel-cage type of electric motor for this class of work. Details of the cost of the different portions of the installation would be instructive.

With reference to Mr. Preece's remarks regarding the economy of using producer-gas for generating electricity, Mr. Thorp considered that he had under-rated the economy of this system. One ton of coal, if burnt in a well-designed producer and used in a similarly proportioned gas-engine would generate 1,300 to 1,500 kilowatt-hours, but it was doubtful whether any steam-plant in regular work

would develop more than 750 to 800 kilowatt-hours per ton of similar coal. The extensive tests recently carried out by the Geological Department of the United States Government had resulted in showing that 2·65 times as much coal was used in a well-designed steam-plant per electrical horse-power as in a similarly designed gas-producer plant, the fuel used in all the tests being of the same quality. The statement that a low and varying load-factor reduced the efficiency of a gas-plant to a greater extent than it did that of a steam-plant was surely not correct. The out-put of a well-designed gas-producer could be varied or entirely shut down by simply reducing the blast, and the producer could be put into full blast again when required, with considerably less waste of fuel than in the case of steam-boilers. Dr. Edward Hopkinson, in his evidence before the Royal Commission on Coal-Supplies in 1903, gave it as his opinion that the electrical power-station driven by producer-gas would be the power-station of the future, not so much on account of the inherent greater theoretical efficiency of the system when working under full-load test conditions, as on account of the much smaller effect of the fractional load-factor, and the financial saving due to the use of cheaper coal. It would be interesting to hear for what reasons Mr. Preece considered the efficiency of the producer-gas plant to be affected more seriously by a low-load factor than by a steam-plant. Mr. Thorp.

Mr. Kellow, in reply, concurred with Mr. Hayes in thinking that producer-gas plants had many and important claims upon the attention of quarry- and mine-owners (particularly where the cost of fuel was high), but he thought that their province would generally be where steam-plants were the only alternative. Large initial outlay, high cost of maintenance, and rather complicated mechanism, might, however, be cited as objections to their use, while the difficulty of speed-regulation made the gas-engine a far from ideal type of prime mover when applied to driving an electric generator. Where the local conditions varied so much, the cost of water-power would vary also, within wide limits, but in the majority of cases it would be found less costly to install, and more satisfactory to work on, than any other system. To avoid misconception he might state that he had not intended to convey in his Paper the idea that each separate slate-property possessed the essentials of a complete hydraulic system, but only that there was an abundance of water-power available in the district generally for the needs of the slate-industry. While agreeing that where the power-house was located a considerable distance from the available water-supply the cost of conveying the water might be high, he regarded as of Mr. Kellow.

Mr. Kellow. comparatively minor importance the cost of transmitting electrical energy from the power-house to the point of application, as with a three-phase system and a suitable voltage, this could be done very economically over any distances required in the slate-districts of North Wales. He was pleased to note that Mr. Hayes was in accord with him as to the utility of electrical distribution of power in slate-mines and quarries, but it was not quite obvious why he considered the choice of gas as the primary source of power should "tend to determine the rival merits and demerits of the different systems of transmission." If the conditions were as Mr. Hayes assumed them to be, namely, that the distributing portions of the plant would be placed close to the points where the power was required, there would be no necessity for high voltage nor for the use of transformers in conjunction with a three-phase system; so that the superiority assumed for the continuous-current system in these respects could not be substantiated. Replying to Mr. Thorp, the alternative of an open channel and shorter pipe-line was usually a cheaper method of construction than laying a pipe-line the whole distance between the reservoir and the power-house, but the Croesor installation was an exception to the rule, as the channel would have had to be cut in solid rock almost the entire distance. Moreover, with a variable load the open-channel method was more wasteful of water, as sufficient had to be let out of the reservoir to meet maximum requirements, and the difference between the actual requirements and the maximum had to be allowed to run to waste. With a pipe-line directly connected to the reservoir such waste did not occur. The governor in use was of the ordinary centrifugal type, very sensitive in action, and operated a freely-moving piston-valve, which controlled the flow of water to a hydraulic cylinder, containing a piston directly connected to the spear in the nozzle. An additional and valuable feature was a device for regulating the rate at which the spear could be inserted and withdrawn. A separate adjustment was available for each direction of motion. The time-factor was important. It was a mistake to allow a governor to act too quickly, as the inertia of the column of water had to be reckoned with, causing as it did pressure-variations which neutralized the action of the governor and set up hunting. The secrets of success consisted, in his opinion, in operating the governor slowly when shutting off water, minimizing pressure-variations by a good air-vessel or its equivalent, and providing sufficient fly-wheel effect to keep the speed within the required limits during the period the governor was acting. In the Croesor plant the load was very fluctuating, sudden changes of 30 per cent. to 50 per cent. being

experienced throughout the day. The maximum speed-variation under these conditions was 4 per cent., which he regarded as satisfactory. With reference to the Pelton buckets of the "A" type, the efficiencies of which were given in *Fig. 9*, they were not fixed radially as Mr. Thorp inferred, but with a backward slope, according to the practice of the best makers. Constructing the front lip in concave form did not, in Mr. Kellow's opinion, obviate the numerous objections to this type, but as he had explained his views thereon at considerable length he was unable with advantage to add to what he had already said. He referred Mr. Hayes and Mr. Thorp to the figures furnished by him in his reply to the discussion regarding capital outlay and working-expenses. He considered the points they had raised very apposite and their remarks a valuable contribution to the discussion. Mr. Kellow.

Mr. PREECE, in reply, regretted that he was unable to supply details of the prop used in the German colliery. As regarded the cost of working at the Wintershall plant, current was obtained from a water-power-plant, but assuming it cost ½*d.* per unit the value of the current used in lifting 657 tons was £3 4*s.* The capital cost of the winding-plant was about £3,500; allowing interest, redemption, and depreciation at 10 per cent. and assuming 250 working-days per annum, the daily cost was £1 8*s.* Labour might be taken at £1 per day, hence the total cost was £5 12*s.*, which was equivalent to 2*d.* per ton lifted. Mr. Gillott's figure came to 1·78*d.* per ton, but it was not clear how much he had allowed for capital charges. As to the efficiency of producer-gas plants, there was no doubt that such plants could vary their output, but in such cases the full efficiency was lower. It was a matter of general experience also with those working internal-combustion engines that the efficiency was very low at loads below half-load. Gas-engines had to be considerably improved before they could compete successfully with steam-turbines. Mr. Preece.

9 April, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

The Council reported that they had recently transferred to the class of

Members.

Burnet Adams.
George Gray Anderson.
John Taylor Babtie.
Harry Robertson Best, M.A. (*Oxon.*)
Athol John Capron.
Alfred Dover Delap.
Herbert St. John Durnford.
Somers Howe Ellis.
Charles Ernest Vere Goument.
Robert Green.
Robert Falkland Harvey.
George Patrick Hayes.
Edward Hooper.
John Charles Mills.
Diogo Andrew Symons.
John Stuart Ellis de Vesian.

And had admitted as

Students.

Eric Pearson Adair.
Sydney Harold Arbon.
Gerald Tinlin Arnold.
Charles Edward Cecil Baillie.
Florian Acworth Baker.
William Baker.
John Barber.
Roderick George Bartholomew.
William Henry Beeston.
John Aiton Bell.
James Kingsley Bell.
Arthur Charles Bonsor.
Henry Adair Bridge.
George Ernest William Broade.
David Brown, Jun.
Harold Worsley Brown.
Francis Robert Burfield.
Percy Clement Burnett.
Francis Jenkinson Button.
Victor Charles Douglas Boyd Carpenter.
Henry Bradshaw Carswell
James Bryden Christie.
Ivor William Clarry.
Leslie Horace William Crockwell.
Austin Cyril Croskell.
Arthur Stephen Crow.
Hans Raj Dogrā.
Edmund Alexander Drabble.
Daniel Dugdale.
Peter Eckersley.
Charles Brownlow Fairbairns.
Philip Norrison Fawcett.
James Folds.
Arthur Allison Fordham.
Harold Percy Forge.
Dudley Collins Francis.
John Kilgour Grant.
Charles William Tandy Green.
Johnbaptist Robert Green.
Walter Dunross Goudie.
William Morland Gyles.

Students—continued.

James Harston.
John Douglas Hawkes.
Frank Herbert Holloway.
John Vincent Howard, B.Sc. (Eng.) (*Lond.*)
Philip Hoyland.
Frederic Hughes.
Arthur George Ingham.
George Ingram.
Charles Edward Jefferis.
George Reginald Montague Jennings.
Archibald Septimus Knox.
Henry Wilfred Lawson.
Thomas Henry Leader.
Bernard Robert Leapingwell.
Hubert Llewellyn Lewis.
Francis Lewis.
Rowe Crompton Morrish Lewis.
William Stanley Lloyd.
Alexander Lyell, Jun.
Archiebald McCurdie.
Walter George McFadyen.
John Mackinnon.
Kingsley Douglas McMillan.
Harry Marshall.
Eric Walton Merrall.
Hugh Milman.
Charles Stewart Morel.
Joseph Robinson Moreton.
George Michel Moubayed.
John Mulcahy.
Norman Murray.
William Robert Jardine Murray.
Harry Leslie Norman.
Cecil Joseph Parker.
George Stewart Paton.
John Haggie Patterson.
Frank Joseph Payne.
William Harold Pirrie.
Leonard Percival Platt.
Reginald Camden Pratt.
Wilfred Harry Pryce.
George Dudley Rae.
Adolphe Emile Ragot.
Henry Norman Christie Renner.
Charles George Gordon Robson.
Cyril Sivewright Saunders.
Thomas Hardman Seaton.
Herbert Hugo Schneider.
Percy George Smales.
John Reid Smith.
James Edwin Norman Smithson.
Alexander Maclean Stewart.
Harry Willoughby Oddin Taylor.
John Hobbs Thorpe.
Ernest Timothy.
Richard Gilson Trower.
Felix Duncan Tunnicliffe.
John Altabon Guise Tyndale.
Wilfred Thomas Walker.
Cuthbert Rennie Weatherell.
Lewis Charles Saxby Wellacott.
Arthur Harwood Wells.
Wilfrid Leicester Whitaker.
Howard Moncaster Whitley.
John Grove White.
Thomas Watkin Wishlade.
Edmond William Woods.
Stanley Yates.

The Scrutineers reported that the following Candidates had been duly elected as

An Honorary Member.

The Right Hon. Lord Viscount Milner, P.C., G.C.B., G.C.M.G., M.A., D.C.L. (*Oxon.*)

Members.

Charles Henry Barratt.
John Burlinson Grant.
Professor Henry Louis, M.A. (*Durham*).

Associate Members.

Reginald Herbert Adams.
Matthew Edmund Moore Anderson, B.A. (*Cantab.*)
David Quintin Bell.
William Blackadder, B.Sc. (*Edin.*)
Talbot Cottom Broom, Stud. Inst. C.E.
Frank Broomfield.
Frederick William Carter, M.A. (*Cantab.*)
Archibald Barron Cathcart.
Thomas Evan Arthur Caton.
Osmond Cattlin.
Alexander Spence Chalmers.
John Clegg.
Austin George Cooper.
Arthur Laurence Cox.
John Crocker.
Edward Harold Crump.
James Diggle.
Charles William Dimes.
John Howard Dixon, B.A. (*Cantab.*)
Harry Duncan.
Thomas William Eayrs.
Rupert Edward Francis Fawkes.
William Arthur Foster.
Francis Hubert Goadby.
William John O'Grady Gill.
Howard Goodfellow.
Frederick Simmons Grogan.
Arthur Alexander Hall, B.A., B.E. (*Royal*)
Walter Sidney Harvey.
Willie Clifford Hawke.
Riddle Hedley.
Francis Greame Holmes.
William Holt.
Edwin Hope.
Thomas Hollis Hopkins.
William Henry Humphreys.
Frederick William Jones.
John Duncan Keith.
Alexander Kerr.
Arthur Noel Lancaster, Stud. Inst. C.E.
George Philip Lee.
John Alexander Main.
Frederick John Mallett.
John Alexander Moore, B.E. (*Royal*).
Henry Thornton Newbigin.
Percy Newton.
Edward Thomas Newton-Clare, B.A. (*Cantab.*), Stud. Inst. C.E.
Hamish Norman Ogston.
Ignatius O'Sullivan.
George Stephen Perkins.
Cecil Henry Roberts.
Robert Guthrie Russel, B.Sc. (*Edin.*)
George Greig Sinclair.
Frederick Slaughter.
George Sturrock.
Robert Milne Thompson.
Harold Frank Vial.
Oswald Wans.
Edward Stephen Warmington, B.A. (*Cantab.*), Stud. Inst. C.E.
Frank Wilmot Watson.
John Racker Webb, Jun.
Arthur Smith West.
John Robert Wharton, B.A. (*Cantab.*), Stud. Inst. C.E.
James Williamson, Stud. Inst. C.E.

The discussion upon the Papers by Messrs. Kellow and Preece on "The Application of Hydro-Electric Power to Slate-Mining" and "Electrically-driven Winding-Gear, etc.," respectively, occupied the evening.

16 April, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

(*Paper No. 3483*).

"The Pyrmont Bridge, Sydney, N.S.W."

By Percy Allan, M. Inst. C.E.

The old Pyrmont Bridge crossing Darling Harbour—an arm of Port Jackson extending into the heart of the City of Sydney—was constructed by a private company in 1857 at a cost of £75,830.

The Government purchased the structure in 1884 for £49,600, when the tolls—then valued at £10,000 per annum—were abolished. Seven years later competitive designs were invited for a new bridge on the south side of the old structure, and, after adjudication, premiums amounting to £1,200 were awarded by the Advisory Board of Engineers. No further action was taken until early in 1894, when the question of "the removal of the old bridge and the construction in its place of certain other means of communication" was referred by the New South Wales Parliament to the Parliamentary Standing Committee on Public Works for inquiry and report.

The conditions upon which the competitive designs were based only called for a swing-span affording a 38-foot deck and two 60-foot fairways, which—in view of the vehicular traffic having increased by 40 per cent. in 5 years, and the utilization of the harbour by vessels of 4,500 tons—was considered inadequate, and led to the Department of Public Works submitting to the Committee a design for a steel bridge with a swing-span of 54 feet, affording two 70-foot clear fairways.

After prolonged inquiry and the consideration of about twenty-six schemes, the Committee decided in favour of the design submitted by the Public Works Department, with timber in lieu of the steel side spans originally recommended.

The foundation stone of the new bridge was laid by the Hon.

E. W. O'Sullivan, State Minister for Works, on the 6th September, 1899; and the bridge was opened for traffic on the 28th June, 1902, by His Excellency Vice-Admiral Sir Harry Holdsworth Rawson, K.C.B., Governor of New South Wales.

The new bridge and its approaches extend from Sussex Street on the City side to Murray Street on the Pyrmont Shore (Fig. 1, Plate 3), a distance of 1,825 feet, the length of the main bridge being 1,210 feet. A steel overbridge, affording three 30-foot clear openings for the vehicular traffic to the wharves, is provided in the Sydney approach, whilst on the Pyrmont side the railway to Darling Island passes under a steel bridge of 25 feet span. The clear headway under the side spans is 26 feet above high water, which meets the requirements of the tugs and lighters visiting the railway wharves above the bridge.

Pivot-Pier (Figs. 2 and 3, Plate 3).—The five bore-holes sunk on the site of the pivot-pier passed through an average of 3 feet of mud and 25 feet of arenaceous clay before reaching the sandstone rock, which had a dip of 8 feet in the diameter of the pier. With such a large body of clay it was determined to sink a wrought-iron caisson to the rock by open dredging, to pump out then the water within the caisson, and to excavate a trench in the sloping rock sufficient to enable the whole periphery of the cutting edge to be bedded on the solid.

The caisson, 42 feet in external diameter, 32 feet in internal diameter, and 53 feet 1½ inch long, is founded 54 feet below low water, and is formed of two concentric rings of plating connected with angle-bar bracing, the inner ring being splayed out at the bottom to form the cutting edge. The plates vary in thickness between ½ inch and $\frac{5}{16}$ inch, the outer ring—to ensure verticality in sinking—being plumb for a height of 27 feet, with circumferential butt joints and countersunk rivets; in the remaining length of outer ring and in the inner ring from bell mouth to top, the circumferential joints are lapped "in and out" with cup-headed rivets. All the vertical joints are butted, with cup-headed rivets for the whole length of the caisson, it being considered that the clay would swell sufficiently to prevent leaks in sinking due to the projecting heads. All joints were caulked, and most of the rivets were closed with pneumatic riveters. The walls of the caisson were remarkably dry under 29 feet of water.

The first section of the caisson, weighing 50 tons, was put together directly over the pier-site on a square ironbark frame, the ends of the four sticks being allowed to project and form the eight points from which the frame with its load was suspended

by wire ropes from the protecting platform, already in position. The ropes were simply passed over and under rounded timbers spiked to the top of the platform and the underside of the frame, and were eased away by hand by twelve men until (after 4 hours) the caisson floated with a draught of 7 feet 3 inches. Fresh sections were quickly built on, and sinking was proceeded with by depositing concrete between the shells, each foot of concrete increasing draught by 2 feet 1 inch. When within a few inches of the bed of the harbour, the caisson was brought into correct position by folding wedges working between long timber guides bearing against the side of the caisson and the piles of the platform; concreting was then rapidly proceeded with at the bottom of a tide, so that with the next ebb the caisson was quietly grounded in a true position and with sufficient weighting to prevent it from lifting.

The material within the caisson overlying the rock was excavated with a bucket dredger worked by a floating crane, and no difficulty was experienced in controlling sinking or keeping the caisson level, a result which the Author considers to be due to the plumb sides adopted as much as to any uniformity in the strata. Advantage was derived from the expedient of having four draught-gauges painted on the inner wall, the cut of the water showing at a glance any movement out of level, and enabling prompt action to be taken by dredging and weighting to counteract the deviation. The greatest amount out of level up to the time of pumping out was $5\frac{7}{8}$ inches in 42 feet. By excavating in the middle below the level of the cutting edge, it was generally found that the weight of the caisson forced the material into the "well" and allowed of very gradual and uniform settlement, working within 5 feet of the inner wall being rarely necessary until nearing the rock, when dredging on the high point of the rock was conducted as close to the inner wall as possible, a good band of clay being left on the low side for the cutting length to bed in when the water was pumped out of the caisson.

Upon pumping out, the caisson listed 11 inches out of level, but only two small leaks showed, and these were easily dealt with by a small pulsometer. No time was lost in excavating the rock on the high side, and in 48 hours the caisson was lowered 2 feet, when a blow occurred, the water filling the caisson in 20 minutes and bringing with it a small quantity of sand and mud, the vertical line of the caisson, however, not being altered.

The Author is of opinion that had some clay been available for placing round the caisson, the leaks, small as they were, would not have developed into a blow.

Although the contingency of excavating the rock by divers and depositing the bottom 12 feet of concrete through the water had been provided for, yet the advantages of a dry foundation were considered so desirable that another effort to pump out the caisson was decided upon. A large bank of clay was placed in position surrounding the caisson, and the excavation of the remaining 6 feet of rock by "jumpers" was proceeded with.

A jumper formed of an ironbark pile 64 feet long, carrying on its end a heavy steel casting provided with three steel cutters, was used for excavating the rock from the line of the inner wall 5 feet inwards; the jumper was hoisted vertically by a steam crane and was tripped in the usual way with a 6-foot to 8-foot drop. On obtaining a face with the vertical jumper, the rock under the bell-mouth and cutting edge was removed with a jumper formed of a flat-footed rail having a steel chisel-point bolted to its lower end; this jumper worked within a hollow chute furnished with a wrought-iron plate upon which the flat foot of the rail rested and worked. By means of guys fastened to the bottom and top of the chute, the jumper could be set at a sufficient angle to reach anywhere under the bell-mouth or cutting edge, the position of the cut being directed by a diver; the jumper was hoisted with a steam-crane and was tripped with a drop of 10 to 12 feet. The jumpers, although slow, did their work well. Divers were employed to clear the rock at the back of the butt straps, the cup-headed rivets in these straps, as well as in the vertical seams, causing some trouble and necessitating more cutting back than would have been required had flush riveting been adopted.

During the course of excavation, the water was usually kept near the top of the inner wall, and upon the rock being cleared for 10 or 12 inches in depth the water was pumped down about 23 feet and the caisson was allowed to settle; this process was followed until the contract-depth was reached, the caisson having in the meanwhile been gradually straightened until it was finally only 2¼ inches out of level with the cutting edge in its correct position, and the top was well within the margin of 12 inches allowed for errors in placing and sinking.

The few places where the cutting edge was not bearing on the rock were cleaned with a water-jet, and the space was filled with fine rich basalt concrete deposited in bags and packed by divers. Around the caisson, for a distance of 4 feet from the outer shell, rings of concrete bags were laid, headers and stretchers, to a height of 4 feet, the space between the ring of bags and the cutting length being filled with concrete deposited loose by means of a bell-mouthed canvas bag

lowered through the water and tripped by divers when in position. This work was carried out in eight sections to ensure the rock being well washed off with the jet before concreting. In order to stiffen the concrete under the bell-mouth, a circular sand-bag wall was built 11 feet inwards from the outer shell, and concrete was deposited in the space through 50 feet of water by automatic self-tripping boxes. This work also was carried out in sections, and after it had been allowed to set for 9 days the water was pumped out of the caisson in 12 hours.

After the water had been pumped out the sand-bag wall was removed and the rock and concrete were thoroughly washed with a jet, the concrete being found to have set very hard and to have been well placed by the divers. Three small leaks were apparent, and were collected in 3-inch iron pipes surrounded with neat cement and led to a sump. Sandstone concreting was then carried on night and day up to 12 feet above the cutting edge. From this point to the top, the interior of the caisson was filled with rubble sandstone concrete, the plums weighing up to 3 tons. The water in the sump was easily kept down, and the concrete was laid in the dry without trouble. The sump was carried up to low-water mark before being finally filled.

On the completion of the masonry the temporary caisson which extended 2 feet above high-water mark was removed, leaving nothing but the stonework of the pier visible.

The proportions and cost of concrete used in the pier are given in Table I of the Appendix.

The total weight on the foundations of the pier, neglecting friction and buoyancy, is 6,800 tons. The time taken in sinking the caisson was 9 months, of which 7 weeks were occupied in reaching the bed of the harbour, 11 weeks in passing through the 24 feet of material overlying rock, and 4½ months in sinking the last 6 feet to the contract-depth.

Rest-Piers.—The Pyrmont rest-pier is founded on the rock, whilst the Sydney rest-pier is carried on fifty-eight piles driven to the rock bottom about 64 feet below low-water mark.

At the site of the Sydney rest-pier an area somewhat larger than the pier was excavated with a ladder dredger until a level clay bottom was obtained 32 feet below low-water mark. The foundation-piles —finishing alternately 2 feet and 3 feet 6 inches above the excavated bottom—were then driven with a follower until the rock was reached, when, by tapping out bolts which passed through the four projecting flitches and the pile-head, the follower was released by a diver. Some of the piles, with the follower, measured 78 feet in

length, but no difficulty was found in pitching or keeping them in place. The follower, which was used repeatedly, was provided with a ring at top and bottom, but no ring was used on the pile-heads, the toughness of the ironbark timber preventing trouble from brooming or splitting.

To ensure the guide-piles being driven correctly, a rectangular hardwood frame was lowered on to the bottom and was held in place while the guide-piles were driven 10 feet. The frame was then removed. Each set of horizontal walings, after being fitted with a guide passing round each pile, was bolted to vertical Oregon runners, by which the walings were forced below water. Successive sets of walings about 5½ feet apart were bolted to the runners and forced down until the bottom was reached. Vertical sheathing of hardwood was next lowered in 6-foot sections, the back of each section being provided at each waling with two battens blocked off and set at an angle, so as to draw the sheathing hard up against the waling when forced down from the top.

When the sheathing was completed, the silt which in the meanwhile had settled between the heads of the foundation-piles was removed by divers, the marine growth being also cleared off the pile-heads. Sand equivalent to a depth of 6 inches was then deposited over the whole area of the pier and a clean bottom was thus obtained.

Between the pile-heads, the concrete was deposited through the water in long timber boxes, fitting the space between the piles and provided with top and bottom doors: these boxes were guided into place by divers and pumping. Above the pile-heads and up to within 2 feet of low-water mark the concrete was deposited through the water in single-rope self-tripping iron boxes designed by the Author with a view to reduce disturbance. Each box, holding 22 cubic feet of concrete, was provided with top and bottom doors, the latter being set on an angle and suspended on the outside of the box from the crane-rope, so that on reaching the bottom the slackening of the rope allowed the weight of the concrete to force open the doors and to bring into engagement the two hooks with which the box was hoisted with the doors hanging free. Although these boxes did their work well, the Author is of opinion that, where suitable gear is available, boxes of a larger capacity would be preferable. The work of concreting was carried on continuously through the water until its completion, the 1,850 cubic yards in the bases of the two piers being finished in 19 days.

This expeditious placing of the concrete minimized trouble from slurry, but in a few instances slurry formed and was removed by

divers. In depositing the concrete, it was generally kept with a slight dip towards the centre so as to avoid the risk of slurry forming face cavities. After the concrete had been allowed to set for 14 days the dam was pumped out, and a fair amount of slurry of the consistency of chalk was removed before the remaining 12 inches of concrete in the bases of the piers was deposited in the dry; the masonry work starting from 1 foot below low-water mark was also laid in the dry.

On the completion of the piers the timberwork was removed and a rigid inspection of the surfaces was made by a diver, the piers being reported to have a smooth face and to have set very hard, a report which the Author's subsequent inspection of one of the piers confirmed. The proportions and cost of concrete and the prices of materials are given in Table I (Appendix).

Swing-Span (Figs. 2 and 4, Plate 3).—The swing-span consists of four main girders with horizontal top and curved bottom booms, 223 feet long, 15 feet deep at the centre and 5 feet deep at the ends, spaced 13 feet 4 inches apart and rigidly braced together over the pivot-pier and at the ends, whilst vertical and diagonal bracing connect the top and bottom booms at intermediate points. The girders are also connected at their upper panel-points by cross girders carrying a rolled-joist and buckled-plate deck, the buckled plates being riveted to the projecting bottom flange-plates of the top booms, which gives the rigidity so desirable in a high-speed swing-span. Upon the steel deck is laid coke concrete, covered with tallow-wood blocks on the carriage-way and asphalt on the footpaths.

The swing is of the rim-bearing type, the whole weight, 800 tons when swinging, being distributed by means of eight small girders to sixteen equidistant points on the drum.

The swing-span is designed to carry a distributed live load of 100 lbs. per square foot of deck, and a concentrated load of 20 tons on a 10-foot by 5-foot wheel-base. The main girders were calculated to have a deflection of 4 inches, and the actual deflection is $4\frac{1}{4}$ inches; but as the maximum stresses over the pivot-pier occur when the bridge is swinging, the ends are lifted only $1\frac{1}{4}$ inch, the dead load taken by the cams at each end being about 40 tons, which reduces the time of lifting, and is sufficient to prevent chattering due to heavy loads concentrated at the ends.

The span was built out from the pivot-pier without staging, a stationary crane on the platform alongside raising the material to a crane travelling on the top of the span, by which the different members were placed in position.

To avoid the cracking of the cement rendering upon which the wood blocks are laid, the ends of the swing-span were weighted to give an equivalent deflection to that produced by the blocks, the rendering was then completed, and the weighting was gradually removed as the laying of the blocks proceeded.

Turn-table.—The drum, which is 35 feet in diameter and 5 feet deep, is provided with sixteen radial struts connected at their inner ends to two disk plates fitted over and revolving about the cast-iron pivot. A steel coned tread is secured to the underside of the drum and bears on sixty-six cast-steel rollers, 10½ inches wide over all, with a bearing width of 10 inches face. The rollers are connected with 1¼-inch radial rods to two circular disk plates revolving about the pivot with ¼-inch play, the whole forming a flexible turn-table.

The bottom tread is of the same section as the top tread, and is secured to a cast-iron track of bridge section machined top and bottom, and bedded hard on the masonry. It was not found practicable to machine the treads and track without building a special lathe with a rigid face-plate or table at least 37 feet in diameter. It was therefore determined to construct a special attachment to a planing-machine, and to plane each section of the tread separately to the correct radius, and to fit the sections together afterwards to form the circle.

Some weeks after the opening of the bridge for traffic, the pivot was found to be moving with the turn-table, due to the drawing of the holding-down bolts and some slackness in the bolt-holes. This was rectified by the addition of four wrought-iron keeper-plates 8 inches wide by 1¾ inch thick, with the outer edges turned down 3 inches. The plates rested on the bed-stone, the lip being let down into the stone, whilst the circular inner edge bore against the bottom flange of the pivot, the thrust from the pivot being taken by the back of the lip bearing against the bed-stone, and the keeper-plates being held down by a couple of 1¼-inch bolts run in with lead. Very great care was taken in fitting these plates, and when in position, the bed-stone was covered, and the pivot surrounded up to the top of the bottom flange, with rich concrete.

Much trouble was experienced through the rollers seizing and tearing off the ends of the radial rods, caused by the iron borings which had not been thoroughly cleaned out of the tapped holes for the grease-cups finding their way with the grease on to the rods. This caused scoring and eventually seizing of the rods, which in the first instance were too neat a fit. Also, the gun-metal nuts against which the rollers bear had no oil-runs; and whilst the lock-nut was effective when opening the swing, yet, in closing it, the friction of

some of the rollers was sufficient to make the gun-metal nuts revolve with the rollers until the ends of the radial rods were torn off.

Accordingly the rods were straightened, some were welded, and all were turned down $\frac{1}{16}$ inch. Oil-runs were also cut on the rods and gun-metal nuts, whilst the links connecting the outer ends of radial rods were slotted $\frac{1}{2}$ inch at each end and provided with machined fillers; so that by knocking back a filler the links can now be taken off without having to free three radial rods, as was previously necessary for the removal of a single roller.

A long delay was occasioned through the rods and rollers not being interchangeable, as it was necessary to replace every roller on its own rod. To prevent the running back of the bearing nuts, small inverted U-shaped steel castings have been provided, with a claw fitting the nut like a spanner, whilst lugs on the castings, machined to fit under the bottom edge of the connecting links, take the pull. During 3 years after these alterations were made the bridge was swung 18,816 times without a hitch, or any expenditure on repairs, whilst the even distribution of the weight on the rollers is shown by the absence of any idle roller in the ring.

Motive Power.—The machinery both for sluing the swing-span and for lifting its ends, as well as for working the roadway-gates on the side spans, is actuated by electric motors driven by current supplied from the tramway power-house about $1\frac{1}{2}$ mile from the site, and controlled from a small house situated over the footpath at the centre of the swing-span. The motors, controllers, and electrical apparatus generally, so far as the conditions permitted, are of the tramway type adopted by the Railway Commissioners of New South Wales, which ensures duplicate parts being always available, and speedy replacement or repairs. The potential of the current ranges from 550 to 600 volts.

The two 50-HP. series-wound motors for sluing the swing-span are of the General Electric Company's standard "G.E. 57" type, and were guaranteed capable of exerting together a starting-effort of 5,384 lbs. at 3·143 inches radius from the centre of the armature-shaft, and, with this load, of attaining an armature-speed of 509 revolutions per minute at the end of 24 seconds without the current exceeding 130 amperes in either motor. An allowance of 100 per cent. upon the calculated maximum effort required at the pitch-circle of the rack in a heavy wind is included in these figures to cover the friction in the gear between the motors and the rack.

The motors are fixed to the machinery-platform within the drum, and drive, through cut steel spur-gearing, a main horizontal shaft carrying at each end a bevel-pinion meshing with bevel-gears (one

looking up and the other looking down) keyed to the tops of the two vertical shafts on the outside of the drum. The vertical shafts carry pinions on their lower ends, which tooth into the rack fixed to the cast-iron track running right round the pivot-pier.

The shafting and gearing is so designed as to allow of either or both motors driving through one vertical shaft, whilst the gear reduction is 1,223 revolutions of the armature to one complete revolution of the swing-span.

In Table II (p. 154) are given the results of twenty runs at different speeds, the maximum effort exerted by the motors to slue the span in 30 seconds having been 89 HP., at a cost of 0·357*d.*; whilst 15 HP. was exerted by the motors for a 69-second run at a cost of 0·221*d.*; the most economical run of the series was one in 55 seconds, at a cost of 0·183*d.*, with a maximum motor-effort of 48 HP. The smoothness of the track and the easy running of the turn-table is shown by the tests, the span in some cases having "coasted" through 70 degrees after the current was cut off.

Auxiliary hand-gear is provided, the 6-foot capstan-bars on deck working two vertical shafts carrying on their lower ends mitre-wheels driving two horizontal shafts having cut pinions meshing with the large cut gears keyed to the main horizontal shaft. The reduction is 352 revolutions of the capstan-head to one complete revolution of the swing-span.

The armature-shaft of each motor is extended at the commutator end to carry a brake-wheel, the two brake-straps being connected with levers actuated by a screw and hand-wheel worked by the man in the controlling-house. Before the brakes were in working order, the swing-span was occasionally stopped by reversing the controller, but with the amount of back-lash in the gearing this was found to strain the machinery seriously, and resulted on one occasion in the outer bearings of the horizontal shaft being lifted and broken. Heavier cast-steel brackets were substituted, and reversing whilst the span is in motion has been avoided, the hand-brakes alone being now used for slowing the swing.

A mechanical tell-tale driven off the main horizontal shaft shows on a dial in the controlling-house the position of the span, and by this means the point of cutting-off of the current, and the time for application of the hand-brakes is determined. Whilst the wind has an effect on coasting, yet the constant practice enables the operator, after a couple of swings, to ascertain the allowance to be made according to the weather.

In order to take up the back-lash in the gear and to stop the span in its correct position without jar, a latch and catch is provided over

each rest-pier. The latch, carrying on its end a small wheel, is free to move vertically upwards in brackets secured to the swing-span, and is so adjusted by a counterweight as to drop into the recess in the catch with the required velocity. The catch is pivoted and secured at its lower end to a girder on the rest-pier, whilst near the upper end of the catch are placed two heavy coil springs. In closing the span, the latch-wheel meets and rolls up the inclined plane at the top of the catch and drops into the recess, when the momentum of the span brings into play the coil springs, which either bring the ends of the span back into their correct positions, or move enough to allow the latches to release themselves, when, by reversing the controller, the latches are again brought into engagement. If the span be travelling too quickly, the latch-wheels jump the recess in the catches. Preparatory to opening the swing-span the latches are drawn by means of a hand-lever in the controlling-house.

The 35-HP. series-wound motor for operating the end lifts is of the "G.E. 1,000" type with nose suspension, and is situated at the centre of the swing-span. It drives through a cut pinion and spur-wheel a longitudinal shaft actuating at each end, by means of right- and left-hand worm-gearing, two transverse shafts each provided with four cams having 1½-inch throw, which raise or lower the ends of the span 1¼-inch, the remaining 1¾-inch vertical movement in the cams being for lifting the foot-blocks clear of the pedestals on the rest-piers. The gear-reduction is 147 revolutions of armature-shaft to one complete revolution of the cam-shaft. In Table III are given the results of six tests, the cost of raising ends having in one trial been 0·044*d.*, the time taken 8 seconds, and the maximum effort exerted by the motor 29 HP.

For stopping the cams in their correct positions a solenoid brake is provided, with a weighted lever attached to a strap passing over the brake-wheel keyed to the armature-shaft. The solenoid is arranged in series with the motor holding up the weighted lever, and releases it when current ceases to pass, thereby applying the strap brake and stopping the motor, the worm-gearing being suitable for this quick action.

A mechanical tell-tale worked off the main longitudinal shaft shows on a dial in the controlling-house the position of the cams, from which the time of cutting off the current is determined. Although the cams can be worked either way, in practice they are run in one direction.

No difficulty was encountered in ensuring the ends of the span being lifted exactly 1¼ inch, the wedges in the pedestals over the rest-piers permitting of adjustment to the required amount. As

designed, each foot-block was provided with two light springs to keep the pin at the bottom of the eccentric in line with the centre of the cam-shaft; these springs were, however, ineffective, allowing the eccentrics to slide the foot-block along the pedestal without lifting the ends. This was rectified by the provision of four ⅜-inch coil springs to each block, which kept the pins vertically in line, and allowed the cams to do their work without subsequent trouble. Auxiliary hand-gear is provided, worked by capstan-bars on the deck by three men, the ratio of the gearing being 32 revolutions of the capstan-head to one complete revolution of the cam-shaft.

At the junction of the swing with the side spans, the camber of the roadway is worked out so as to give a level cross section of deck. The chequered plates on the terminal girders of the fixed spans overhang the terminal girders on the swing-span and give 1¼ inch vertical clearance when the swing is ready for opening; the lifting of the ends brings the terminal girders on the swing-span hard up against the underside of the chequered plates on the fixed span.

Gate-Machinery.—To avoid the provision of separate mechanism, the hinges of each footpath-gate are keyed to the spindle of the roadway-gate: the two gates thus work as one, the spindle being extended to the machinery-platform underneath the deck of the side spans.

For each pair of gates a 5-HP. four-pole series-wound motor of General Electric type, running at 1,200 revolutions per minute, drives, through a bevel-pinion and gear, a longitudinal threaded shaft, carrying a gun-metal travelling nut having projecting pins at top and bottom. These pins pass through, and work in, long slotted holes in two wrought-iron bars, the upper one being cranked down and bolted to the lower, which is extended and is keyed firmly to the bottom of the gate-spindle, and forms the lever for moving the gates. Attached to the underside of the lever is a copper loop which—at the open and closed position of the gates—engages with and short-circuits two adjustable brass springs secured to the floor of the platform, thereby energizing an auxiliary tripping-coil on the circuit-breaker in the controlling-house, which cuts off the current from the motor. The motor being supplied with a solenoid brake, the cutting off of the current causes a weighted lever to drop and stop the motor: the brake-lever is attached to a strap passing over a brake-wheel keyed to the armature-shaft. When the controller is reversed and current applied, the solenoid, which is in series with the motor, lifts the weighted lever and releases the brake. For 3½ revolutions of the armature-shaft, the nut on the threaded shafts moves 1 inch. Although the gate-

machinery will not permit of movement of the gates other than by revolving the threaded shaft, automatic latches are provided, the gun-metal nuts towards the end of their travel engaging small levers which force up through the centre of the roadway a pair of wrought-iron pins behind and in front of the gates. In Table IV (p. 156) are given the results of nine runs; the time of opening the gate in one of the trials was 18 seconds, at a cost of 0·014*d.*, with a maximum motor-effort of 2·9 HP.

The controller for the sluing-motors is of the standard "G.E., K 11" series-parallel type. The controller for the end lifts and the four for the gate-motors are of the usual rheostatic type, having a separate reversing-barrel on which are placed the additional contacts for interlocking the circuit-breaker with the position of the gates, so that the motors cannot be driven in a wrong direction, whether the gates are open or closed.

Lighting.—There are nineteen arc-lamps on the bridge and approaches, whilst the six arc-lamps on the protecting platform are of the marine type, with ruby globes and guard-cages. The arc-lamps, arranged in series of five, are of the enclosed long-burning type, in which the automatic cut-out and substitutional resistance is contained in the lamp-case itself.

Cables.—The two main cables are brought on poles from the power-house to the Pyrmont end of the bridge, thence along the bottom chord of the side spans to the rest-pier, at which point two lightning-arresters with kicking coils are placed, together with a 300-ampere main switch. From the switch the two armoured submarine main cables pass down the end of the rest-pier and are laid in a trench across the fairway excavated in the bed of the harbour to a depth of 30 feet below low-water mark. The cables are taken thence up the side of the pivot-pier under the track and up through the centre of the hollow pivot, thence to the underside of the footpath, where they enter a wrought-iron box reaching from the curb to the underside of the controlling-house, and they finally pass through hollow cedar pedestals in the inside of the house to their connections with the main bus-bar on the switchboard. Two seven-conductor armoured submarine cables for the two gate-motors, and one for the arc-lighting, laid in a similar manner to the main cables, extend from the controlling-house to each rest-pier; whilst a four-conductor submarine cable is also provided on the Sydney side for the operator's direct telephonic communication with the power house and the City Exchange.

To prevent twisting of the cables (due to the swinging of the bridge) from occurring at the bottom of the pivot, where it would be

difficult to effect repairs, the cables are bunched together and are made fast to the top of the pivot; they are then given a complete coil of large diameter, the coil resting on horizontal wooden rollers carried on the radial struts, which permit the coil to wind and unwind with the movement of the swing-span.

As the sluing-motors are worked on the series-parallel system, and as their direction of rotation has to be reversed, the field- and armature-leads of both motors are brought into the controlling-house, which is accomplished by using an eight-conductor cable. The four leads of the end-lift motors are likewise brought into the controlling-house in a four-conductor cable. Although the wiring in the controlling-house is so encased as to be hidden from view, yet it is readily accessible, and all wires are tagged and numbered.

Switchboards.—The operating cedar switchboard, provided with porcelain insulators throughout, is placed directly over the controllers and carries a 300-ampere main switch; a 250-ampere switch with a 250-ampere circuit-breaker for the sluing-circuit; a 100-ampere switch with 150-ampere circuit-breaker for the end-lift circuit; and a switch for the four gate-motor circuits, with a circuit-breaker for each gate-circuit. A feature of the last-mentioned is that each is provided with an auxiliary tripping-coil connected with the contacts at the gates, so that when once a gate is started the operator's further attention is not needed, the contact when the gate is in position causing the circuit-breaker to trip: it is then impossible to move the gate or to close the circuit-breaker unless the controller be reversed. Weston ammeters are placed immediately over each controller and a 600 Weston voltmeter is placed at the centre of the board. The cedar switchboard for the arc-lighting is placed at one end of the house, and carries a 100-ampere main switch, a 40-ampere circuit-breaker, five switches for the five arc-lamp circuits, two switches for the ten glow-lamps in the house and machinery-room, and a switch for the pilot-light in the house which is in series with two red glow-lamps on the mast-head used for signalling to shipping.

Cost of Power.—The charge made by the Railway Commissioners for the supply of current is 1*d.* per Board-of-Trade unit, the main cables from the power-house having been laid at the cost of the Public Works Department; one complete cycle of operations costs $\frac{3}{4}$*d.*, which includes the closing and opening of the four gates, the lowering and raising of the ends of the span, and the opening and closing of the swing-span, the whole—including the lighting—being controlled by one man in the controlling-house. The detailed cost of operating the swing-span and lighting the bridge

for 4 years is given in Table V, the cost of current for 24,610 openings having been £83 6s. 5d.

Protecting Platform and Dolphins.—A platform built of turpentine piles, 325 feet long and 3 feet 4 inches wider than the over-all width of the swing-span when open, affords protection from passing vessels. Dolphins connected by stout rubbing-strips shield the rest-piers, the platform and dolphins forming two long fairways, which materially facilitate the passage of vessels through the openings.

Side Spans (Figs. 5, Plate 3).—The six ironbark trusses in each side span carry transverse floor-beams on which is laid 6-inch by 4-inch longitudinal planking alternately on flat and edge, covered with tarred metal, to form the road-surface; asphalt is laid on the foot-paths, whilst the wrought-iron parapet is carried from end to end of the bridge. With the heavy traffic the tarred metal has not been a success, and it is being replaced by wood blocks.

The trusses are of the Howe type, in which redundant members have been omitted. As the success of timber trusses is largely dependent on the strength of the bottom chord-joint, it was decided to test the full-size joint in a machine specially designed for the purpose under the direction of Mr. C. W. Darley, M. Inst. C.E. This machine consisted of a heavy ironbark frame and large hydraulic jack, a steam-pump being used for working the jack, whilst a pipe-connection between the jack and a 50-ton testing-machine enabled the results to be read on the latter. In the three tests, failure occurred by the shearing of the bolts and of the timber between the notches, the recorded results showing an ultimate strength of 151 tons, 160 tons, and 182 tons respectively. In making the joints in the actual work, the notches were carefully cut in the timber, and the plates on either side were then cramped hard up. The joint was placed under a steam-drill, the drill passing through the steel plates and the timber in the one action, twelve turned bolts were then driven through the holes to complete the joint, thus ensuring the bolts bearing on the timber and the two plates. The trusses, weighing 15 tons, were put together on the wharf close to the bridge-site and were hoisted about 30 feet on two pile-driving machines, being then towed to the site and placed on the piers. In finishing the bridge, twelve trusses were lifted from the wharf and placed in position in 7 hours, whilst half a pier and two spans with roadway-gates were completed for traffic in 8 days.

Approaches.—The approaches on either side consist of embankments and concrete retaining-walls, the abutments and northern retaining-walls, which are the more exposed to view, being faced with sand-stone, whilst a stone parapet extends the whole length of the approaches. The Pyrmont approach is founded on the rock, whilst

the Sydney approach is for the greater portion of its length carried on 368 piles driven to the rock.

The work was designed by the Author, then Engineer-in-Charge of Bridge Design under Mr. C. W. Darley, M. Inst. C.E., Engineer-in-Chief for Public Works. The Author also supervised the construction of the work under Mr. Darley until his departure for England, by which time the piers were nearly all in place, and subsequently until its completion under Mr. W. J. Hanna, the Commissioner and Principal Engineer for Roads and Bridges.

Mr. H. H. Dare, Assoc. M. Inst. C.E., and Mr. Lincoln Buswell were the Author's principal assistants in the office and on the works respectively.

The cost of the completed work, including all contingencies and engineering expenses, was £112,500, as detailed in Table VI, the rate of wages paid being given in Table VII, and the cost of materials in Table I.

The Author is indebted to Mr. J. Davis, M. Inst. C.E., Under-Secretary for Public Works, for the plans and photographs illustrating the Paper, and to Mr. O. W. Brain, Electrical Engineer for Railways, for advice in connection with the electric equipment.

The Paper is accompanied by twenty-four drawings, from which the illustrations in Plate 3 have been selected for reproduction, and by numerous Tables; also by an album of photographs.

[Appendix.

APPENDIX—TABLE I.—PROPORTIONS AND COST OF CONCRETE.

Position in Work.	Description and Gauge of Stone.	How deposited.	Proportions to 374 Lbs. (1 Cask) of Cement. Stone.	Proportions to 374 Lbs. (1 Cask) of Cement. Sand.	Cost per Cubic Yard in Place.
			Cubic Feet.	Cubic Feet.	£ s. d.
Between inner and outer walls of caisson	Basalt to pass through 1¼-inch ring, and be caught on ⅛-inch screen	Laid in the dry	17	9	1 15 0
Bottom 5 feet of Sydney rest-pier . .	Ditto	Through the water	17	9	2 10 0
Between sand-bag wall and ring of special concrete under bell-mouth of caisson .	Ditto	Ditto	17	9	2 2 6
Bag concrete under cutting edge and special concrete under bell-mouth of caisson	Basalt to pass through 5/16-inch ring, and be caught on ⅛-inch screen	Ditto	11	4	This item was at a lump sum; but on the quantity deposited the cost was 7 8 0
In rest-piers to within 1 foot of low-water mark	Sandstone to pass through 2-inch ring, and be caught on ⅛-inch screen . .	Ditto	17	9	2 2 0
Between inner walls of caisson to a height of 12 feet above cutting edge . . .	Ditto	Laid in the dry	17	9	2 0 0
Hearting in rest-piers from 1 foot below low-water mark to top	Ditto	Ditto	26	11	1 10 0
Abutments and retaining-walls of approaches	Ditto	Ditto	26	11	1 5 0
Hearting in pivot pier from 12 feet above cutting edge to top	As above, with uncoursed blocks of sandstone of not less than 1 foot embedded in the concrete	Ditto	26	11	1 5 0
Foundation of Pyrmont abutment . .	Ditto	Ditto	26	11	1 0 0
Under wood blocks on carriage-way and asphalt on footpaths	Coke to pass through 1¼-inch ring, and be caught on ⅜-inch screen	Ditto	17	11 Coke grit screened through ¼-inch mesh	2 0 0

Cost of Materials delivered on the Works.—Cement, from 9*s*. 6*d*. to 10*s*. per cask; screened Nepean River sand, 4*s*. 10*d*. per cubic yard; basalt and screenings, 7*s*. 9*d*. per cubic yard; sandstone, broken to gauge and screened, 4*s*. 9*d*. per cubic yard; sandstone for masonry quarried ready for working, 1*s*. 3*d*. per cubic foot; turpentine piles, 1*s*. 2*d*. per lineal foot; ironbark foundation-piles, 1*s*. 6*d*. per lineal foot; coke, 16*s*. per ton unbroken; small coke grit (requiring to be broken), 3*s*. 6*d*. per cubic yard; hewn ironbark girders, 1*s*. 10*d*. per cubic foot; sawn ironbark braces, 2*s*. 4*d*. per cubic foot.

TABLE II.—SUMMARY OF TESTS MADE 9TH AUGUST, 1903, SHOWING THE POWER REQUIRED AND COST OF CURRENT FOR SLUING SPAN AT DIFFERENT SPEEDS. CALM DAY. NO WIND.

No. of Run.	Time taken to Slue Span through 83°.	Maximum Effort Exerted by Motors.	Maximum Speed of Armature-Shaft.	Time for which Current was Applied.	Distance Travelled by Span at Time of Cutting off Current.	Distance Coasted by Span between Time of Cutting off Current and bringing Span to Rest with Brake.	Power Consumed by: Motors.	Power Consumed by: Resistances.	Power Consumed by: Motors and Resistances.	Cost of Current for each Run at 1*d.* per Unit.	Time taken to Slue Span through 83°.	No. of Run.
	Seconds.	HP.	Revolutions per Minute.	Seconds.	Degrees.	Degrees.	Watt-Seconds.	Watt-Seconds.	Watt-Hours.	*d.*	Seconds.	
6	30	89	Not recorded	..	..	..	967,800	316,400	357	0·357	30	6
17	47	97	480	14	20	63	575,770	259,430	232	0·232	47	17
18	47	78	580	18	21	62	561,360	302,640	240	0·240	47	18
5	47	72	480	24	40	43	666,640	154,160	228	0·228	47	5
4	47	57	540	26	40	43	598,360	168,440	213	0·213	47	4
8	48	64	500	18	30	53	576,640	269,360	235	0·235	48	8
9	49	74	540	17	28	55	605,540	258,460	240	0·240	49	9
10	51	51	540	30	40	43	555,240	298,840	237	0·237	51	10
7	53	58	480	16	28	55	437,280	318,720	210	0·210	53	7
19	53	78	550	18	25	58	569,520	265,680	232	0·232	53	19
13	54	40	480	26	37	46	524,980	238,220	212	0·212	54	13
16	55	70	480	12	13	70	356,000	335,200	192	0·192	55	16
12	55	72	540	14	13	70	470,160	264,240	204	0·204	55	12
20	55	48	480	22	35	48	479,440	179,360	183	0·183	55	20
14	55	45	530	25	33	50	525,610	219,590	207	0·207	55	14
11	60	67	540	10	14	69	352,960	316,640	186	0·186	60	11
3	64	44	440	25	40	43	542,970	240,030	217	0·217	64	3
21	64	34	480	32	40	43	507,040	252,560	211	0·211	64	21
15	68	62	480	11	13	70	319,700	285,100	168	0·168	68	15
22	69	15	360	45	53	30	408,320	387,280	221	0·221	69	22

Weight of span when swinging 850 tons. Area of floor-space on swing-span 12,000 square feet.
Being slightly on the skew the span is opened only through 83°.

TABLE III.—SUMMARY OF TESTS MADE 9TH AUGUST, 1903, SHOWING THE POWER REQUIRED AND COST OF CURRENT FOR RAISING AND LOWERING END LIFTS.

No. of Run.	Time taken to Revolve Cams through 180°.		Maximum Effort Exerted by Motor.	Maximum Speed of Armature-Shaft.	Power Consumed by			Cost of Current for each Run at 1*d*. per Unit.	Time taken to Revolve Cams through 180°.		No. of Run.
	Lowering.	Raising.			Motors.	Resistances.	Motors and Resistances.		Lowering.	Raising.	
	Seconds.	Seconds.	HP.	Revolutions Per Minute.	Watt-Seconds.	Watt-Seconds.	Watt-Hours.	*d.*	Seconds.	Seconds.	
27	7	..	26	800	75,600	50,400	35	0·035	7	..	27
28	..	8	29	900	132,320	28,280	44	0·044	..	8	28
25	9½	..	22	620	87,480	74,520	45	0·045	9½	..	25
26	..	11	19	620	111,960	111,240	62	0·062	..	11	26
23	10	..	16	700	91,100	142,900	65	0·065	10	..	23
24	..	14	18	480	134,320	99,680	65	0·065	..	14	24

80 tons weight on cams when ends of span are raised full height.

TABLE IV.—SUMMARY OF TESTS MADE 9TH AUGUST, 1903, SHOWING THE POWER REQUIRED AND COST OF CURRENT FOR OPENING OR CLOSING ONE GATE. CALM DAY. NO WIND.

No. of Run.	Time taken to Open Gate through 90°.	Maximum Effort Exerted by Motor.	Maximum Speed of Armature-Shaft.	Power Consumed by Motors.	Power Consumed by Resistances.	Power Consumed by Motor and Resistances.	Cost of Current for each Run at 1*d*. per Unit.	Time taken to Open Gate through 90°.	No. of Run.
	Seconds.	HP.	Revolutions per Minute.	Watt-Seconds.	Watt-Seconds.	Watt-Hours.	*d.*	Seconds.	
9	18	2·9	980	22,620	27,780	14·0	0·014	18	9
10	18	2·3	980	21,210	30,990	14·5	0·0145	18	10
5	18	1·7	910	15,290	40,510	15·5	0·0155	18	5
8	20	2·0	..	22,460	40,820	14·8	0·0148	20	8
1	22	1·5	840	20,664	36,936	16·0	0·016	22	1
3	22	1·5	840	18,760	38,120	15·8	0·0158	22	3
4	24	1·5	840	20,180	39,220	16·5	0·0165	24	4
6	24	1·4	840	20,340	39,420	16·6	0·0166	24	6
2	24	1·5	840	21,770	39,430	17·0	0·017	24	2

TABLE V.—SUMMARY OF CURRENT CONSUMPTION, PYRMONT BRIDGE.

1 July 1902 to 30 June 1906.

Dates.	Number of Openings.	Consumption.	Cost.	Arc-Lamps.	Consumption.	Cost.	Glow-Lamps.	Consumption.	Cost.	Total for Operating and Lighting.	Cost.
		B.T.U.	£ s. d.	Hours.	B.T.U.	£ s. d.	Hours.	B.T.U.	£ s. d.	B.T.U.	£ s. d.
1 July 1902 to 30 June 1903	6,152	6,855	28 11 3	76,915	44,685	186 3 9	24,069	1,622	6 15 2	53,162	221 10 2
„ 1903 „ „ 1904	6,222	4,692	19 11 0	62,795	35,537	148 1 5	22,285	1,781	7 8 5	42,010	175 0 10
„ 1904 „ „ 1905	6,432	4,509	18 15 9	61,415	34,914	145 9 6	22,805	1,822	7 11 10	41,245	171 17 1
„ 1905 „ „ 1906	5,804	3,941	16 8 5	66,070	36,370	151 10 10	33,220	2,222	9 5 2	42,533	177 4 5
Total . . .	24,610	19,997	83 6 5	267,195	151,506	631 5 6	102,329	7,447	31 0 7	178,950	745 12 6

TABLE VI.—SUMMARY OF COST.

	£	£
Swing-span, pivot-pier, rest-piers, protecting platform and dolphins complete—		
Pivot-pier	14,320	
Rest-pier	9,217	
Protecting platform and dolphins	3,379	
Metal-work in swing span including installation of electric equipment	18,293	
Asphalting footpath and wood-blocking carriage-way	1,240	
Controlling-house and painting	777	
Supply of electric equipment	1,649	
Removal of portion of old bridge and sundry extras	352	
		49,227
Side spans, including gates and gate-machinery complete		33,276
Approaches, including steel overbridge in Sydney approach		24,070
Supply and installation of arc-lighting, including lamp-standards		484
Engineering expenses and minor works		5,443
Grand Total		£112,500

TABLE VII.—RATE OF WAGES.

	s.	d.	
Divers	15	0	per day of 6 hours.
Foreman boiler-maker	15	0	,, ,, 8 hours.
,, carpenter	13	4	,, ,, ,,
,, painter	10	0	,, ,, ,,
Masons	11	0	,, ,, ,,
Boiler-makers and riveters outside	10	8	,, ,, ,,
,, ,, ,, in shop	10	0	,, ,, ,,
Blacksmiths	10	0	,, ,, ,,
Carpenters	10	0	,, ,, ,,
Fitters	9	0	,, ,, ,,
Woodpavers, leading hand	9	0	,, ,, ,,
,, ordinary	7	0	,, ,, ,,
Dogman	9	0	,, ,, ,,
Engine-drivers	9	0	,, ,, ,,
Concrete-turners	8	0	,, ,, ,,
Labourers, special	8	0	,, ,, ,,
Attendants on divers	8	0	,, ,, ,,
Masons, labourers	8	0	,, ,, ,,
Painters	7	0	,, ,, ,,
Holders up	7	0	,, ,, ,,
Labourers	7	0	,, ,, ,,
Boys	5	0	,, ,, ,,

(*Paper No. 3666.*)

"Swing-Bridge over the River Avon, at Bristol."

By William Henry Bourchier Savile, Assoc. M. Inst. C.E.

The bridge which is the subject of this Paper conveys both a carriage-road and a double line of railway across the River Avon at a point about ¼ mile above the entrance to Cumberland Basin (*Fig. 1*). It forms an important part of a large scheme of extension carried out by the Great Western Railway Company to deal more effectively with the dock-traffic at Bristol. Before its construction, railway-accommodation was provided only to the wharves on the south side of the Floating Harbour, and all the traffic from these wharves had to join the main line at the Bristol Joint Station where the traffic was very congested. Further, vehicles had no means of crossing the river between Bedminster bridge, and the Clifton suspension-bridge, a distance of about 2 miles, and much inconvenience resulted.

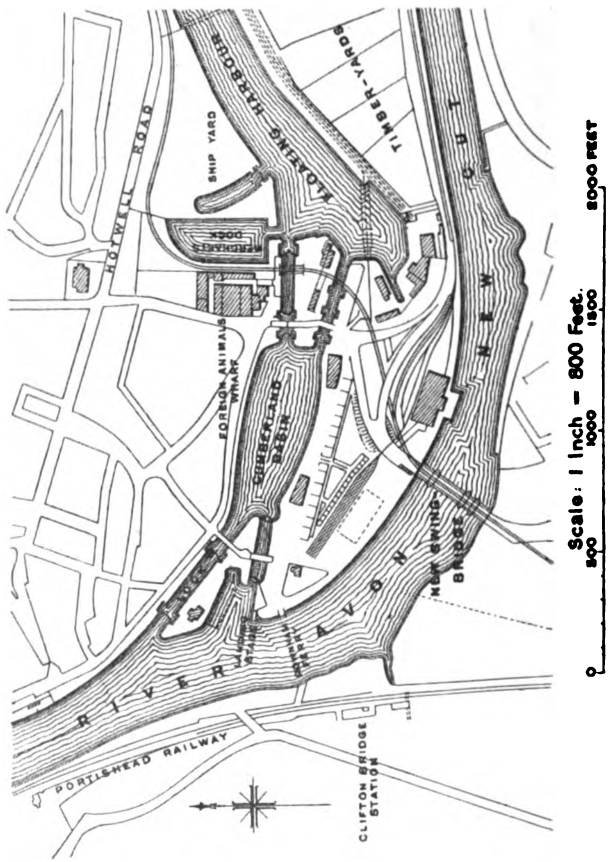
The railway-extensions which necessitated the construction of this swing-bridge included the provision of railway-accommodation to the wharves on the north side of the Floating Harbour, the extension of the railways on the south side to the timber-wharves, and the building of a central goods-depot at Canons Marsh, where dock-traffic can now be marshalled. The bridge provides an outlet for the railway at the west end of the Floating Harbour, and forms a junction with the Portishead branch of the Great Western Railway, whence the trains can join the main up or down line without passing through Bristol station.

Negotiations between the Corporation of Bristol and the Great Western Railway Company resulted in the promotion of a joint Bill in Parliament in the Session 1897 for a combined road- and railway-bridge. The consent of Parliament was duly obtained, but the work

could not be started at once owing to somewhat prolonged negotiations for the purchase of the land on the south side of the river.

The river-traffic for which provision had to be made consists for the most part of the smaller coasting vessels and barges which enter

Fig. 1.



the docks by Bathurst lock and basin. The larger vessels use the deeper lock at Cumberland basin, which is farther down the river than this bridge.

General Description.

The bridge, which the Author believes to be the only double-decked swing-bridge of anything like its size in existence, carries the two lines of railway on the bottom, and the roadway and two footpaths on the top boom. The general arrangements are shown in Figs. 2

and 3, Plate 4. There are two approach-roads on each side of the river which converge before they reach the bridge; the gradient of the approach-roads on the north or Gloucestershire side is 1 in 30, and of those on the south or Somersetshire side 1 in 60. The double-decked type of bridge was adopted in order to avoid level crossings, which would have been necessary if both road and railway had been on the low level.

The swinging portion of the bridge weighs nearly 1,000 tons, and is pivoted on a masonry pier, which will be referred to as the "centre" pier, and which is situated slightly inside low-water line on the south side of the river. The two arms of the swing-span are unequal, being 121 feet 6 inches and 81 feet respectively, and all the river-traffic passes on the north side of the centre pier where there is a clear waterway 85 feet wide. The bridge is turned by hydraulic power, the engines being situated in a house which is supported on columns above the roadway, and which also serves as a look-out tower from which to signal to ships coming up or down the river.

The work was carried out in four contracts, namely, foundations, superstructure, machinery, and interlocking.

Foundations.

The datum line shown in the Figures is 7·58 feet below Ordnance datum; it represents the level of the sill of the old entrance-lock at the Cumberland basin, and is 3 feet above the sill of the new lock. The bed of the river at the bridge is about 2 feet above datum; and at low water, except in times of flood, there is a depth of only about 3 feet of water in the river at this point. The level of high water of ordinary spring-tides is 30 feet above datum, and that of ordinary neap-tides 20 feet above datum.

The principal portions of the contract for the foundations were the north pier and the centre pier, which are both situated in the bed of the river, and had to be constructed inside dams, as it was necessary to found them on the red marl, which overlies the new red sandstone, and which at these points was found at depths varying from 8 to 14 feet below datum.

Before work commenced, the level of the ground on the site of the north pier was about 8 feet above datum, so that it was usually entirely left by the tide at low water. This pier consists of a cement-concrete foundation, about 12 feet 6 inches thick, laid within a rectangular dam, 25 feet by 64 feet 6 inches internal dimensions, or 3 feet larger in each direction than the concrete foundation, and surmounted by a concrete pier faced with masonry in cement mortar.

Each side of the dam consisted of a single row of piles, 12 inches thick, driven as closely as possible and caulked with oakum. King-piles, about 11 feet between centres, with diamond-pointed shoes, were first driven by a pile-engine fixed on a floating pontoon. Stout walings were then bolted on the outside and inside of the king-piles near the top, and also as low down as the mud would allow. Intermediate sheet-piles with shoes were then driven, starting from each king-pile, until they left a space small enough for a closing-pile. Before driving the closing-piles, screw-jacks and wedges were used to force the sheet-piles as close together as possible, and the closing-piles were specially dressed to fit the space left. The closers were usually entirely successful, although in a few instances they required careful caulking before they were quite tight. Additional walings and internal struts were then fixed, and bags of clay were laid about 2 feet deep around the outside of the dam, in order to protect the mud from scour in times of flood. The points of the piles were driven to about 13 feet below datum or about 2 feet below the level at which the foundation was finally laid. The top of the dam was at about 34 feet above datum, so that all ordinary spring-tides could be kept out. At mud-level two sluice-doors were provided, which could be worked from the top of the dam by means of a screw handle working on a long rod attached to the door, so as to allow of water being let in or out as required.

The excavation inside the dam was executed in three lengths, the middle portion being completed, and the concrete laid to a depth of 6 feet, before the end sections were started. The first few feet of excavation was through river-mud, which was followed by silt and stones, overlying a bed of gravel about 6 feet thick; below this was a thin bed of marly clay, and next the red marl on which the foundation was laid, about 10 feet 6 inches below datum. Although the foundation was carried about 3 feet deeper than had been anticipated, it was all safely put in with a very moderate amount of pumping, the only pumps used being a No. 5 and a No. 6 pulsometer. A slight blow occurred during a flood when the masonry was about 2 feet high, but it was easily stopped with bags of clay when the flood subsided. When the pier had reached a level about 6 feet above the sills of the sluices, pumping became unnecessary, as the slight leakage on each tide did not fill the reservoir thus formed, and the water which did get in could be let out through the sluices at low water.

When the masonry had reached the level of ordinary spring-tides the dam was removed by drawing all the piles except a few which

were cut off just above the concrete foundation. Under the maximum distribution of load on the bridge the pressure per square foot on the foundation amounts to 2·9 tons per square foot.

The concrete used throughout this contract is 7-to-1 Portland-cement concrete with a moderate number of displacers. The aggregate was broken Pennant stone and Bideford sand. The masonry facework is of the kind known as rock-faced random-coursed rubble, the stones being square on all beds and joints. The stone used for facework is entirely hard mountain limestone from the Chepstow quarries. The caps to the pilasters are of hard red sandstone from the Forest of Dean, known as Wilderness stone.

The centre pier was built inside a single-pile dam of similar construction to that used at the north pier. The concrete foundation was intended to measure 43 feet by 37 feet, and the internal dimensions of the dam at the top were 3 feet more in each direction. The piles, however, ran inwards somewhat in driving, and the concrete foundation was actually laid solid to the piles. The piles of this dam, as in the case of the north-pier dam, were driven to about 2 feet below the level at which the foundation was finally laid. In order to try to keep the dam water-tight, bags of clay were packed up against the sides to a height of 4 or 5 feet above the mud, and were kept in position by a row of steel rails driven upright into the river-bed about 2 feet 6 inches apart, and about 3 feet from the outer face of the dam.

The excavation proceeded satisfactorily, and two No. 6 pulsometer pumps were sufficient to keep the site dry until a level of 4 feet below datum was reached, when a blow occurred at the south-west corner. This blow was stopped by working tidally, a trench being made on the outside of the dam and filled with clay after the piles had been caulked. This enabled the dam to be pumped out again, and the excavation was proceeded with. When, however, it had been carried 2 feet deeper, another blow occurred, and although many attempts were made to stop the blows, it was not found possible again to make the dam water-tight at high water; the remainder of the excavation was therefore done at low water, when the head was not sufficient to reopen the blows. The sluices were kept permanently open during this period of the work, and an 8-inch centrifugal pump was used, in addition to the two pulsometers, in order to dry the dam as quickly as possible when the tide fell below the level of the sluices.

The head of water above the bottom of the foundation was 18 feet, even at low tide, and at high tide it was as much as 45 feet: it will readily be understood, therefore, that the construction of a water-tight dam presented considerable difficulties, especially as it

was not possible to make a coffer-dam, as the extra width would have reduced the fairway of the river too much.

The excavation was carried out in two sections, and about 12 feet of concrete was laid in the down-stream half before the excavation was completed in the up-stream half. On the completion of the concrete foundation, which is 16 feet thick, the tide was again excluded from the dam and the masonry work was all built in the dry.

The general design of the pier is shown in Figs. 2 and 3, Plate 4. The facework, as in the case of the north pier, is of random-coursed rubble masonry and the backing is of 7-to-1 cement concrete with displacers. The bed-stones on the upper surface, which take the roller-path and centre-pivot castings, are of Cornish granite fine-axed on the bearing-surfaces. The maximum pressure on the foundation of this pier also amounts to 2·9 tons per square foot.

Both the north pier and the centre pier are provided with fender-piling consisting of 12-inch by 12-inch pitch-pine timbers as shown in Figs. 2. In the case of the centre pier, jetties with strongly constructed dolphins at the ends, and of sufficient length to protect the bridge when open, are built on both up- and down-stream sides.

The river end of the south abutment (Figs. 2), on which the rear end of the swing-span bears, is founded on concrete taken down to the marl at a depth of 15 feet below datum, and laid inside a single-pile dam to exclude the high tides. Very little water was encountered until the bed of gravel overlying the marl was reached, after which pumping had to be carried on continuously.

The remainder of this abutment consists of two walls, one on each side of the railway and running parallel with it (Figs. 2). Cross girders, 2 feet deep at the centre, span between these walls, and carry the roadway over the railway until the former bends away towards the east and is carried on an embankment. These walls are of rubble masonry with facework similar to that of the centre and north piers, but are built in lime mortar and founded on 12-inch by 12-inch pitch-pine piles about 45 feet long, which are driven to the marl.

In designing this and all the other piled foundations the maximum load allowed on a pile was 25 tons. The piles were driven with a 1-ton monkey falling 10 feet, until the total set for the last five blows did not exceed 1 inch.

The Towpath pier consists of a small retaining-wall founded on piles, behind which two pits, each 9 feet square at the bottom, were sunk to the level of the gravel bed (which at this point is about 17 feet below datum) and concrete columns were put in. These columns

form the foundation to carry the north ends of the girders of fixed span No. 3 and the south ends of the girders of span No. 2.

Abutments Nos. 1 and 2 of the north approach support the north-approach spans: they are built of rubble masonry similar to that used in the south abutment, and founded on 12-inch by 12-inch pitch-pine piles about 38 feet long. A cross section of abutment No. 2 is shown in Figs. 2.

SUPERSTRUCTURE.

The girder-work throughout is of mild steel of British manufacture, made by the Siemens-Martin acid process, the specified breaking-stress in tension being between 27 and 32 tons per square inch, with a minimum elongation of 20 per cent. on a length of 8 inches.

The working-stresses adopted in designing the various girders were:—

Main girders of swing-span . . .	5½ tons per square inch net, in tension and compression.
,, ,, approach-spans . .	6 tons per square inch net, in tension and compression.
Cross girders of all spans	5 tons per square inch net, in tension. 4½ tons per square inch gross in compression.

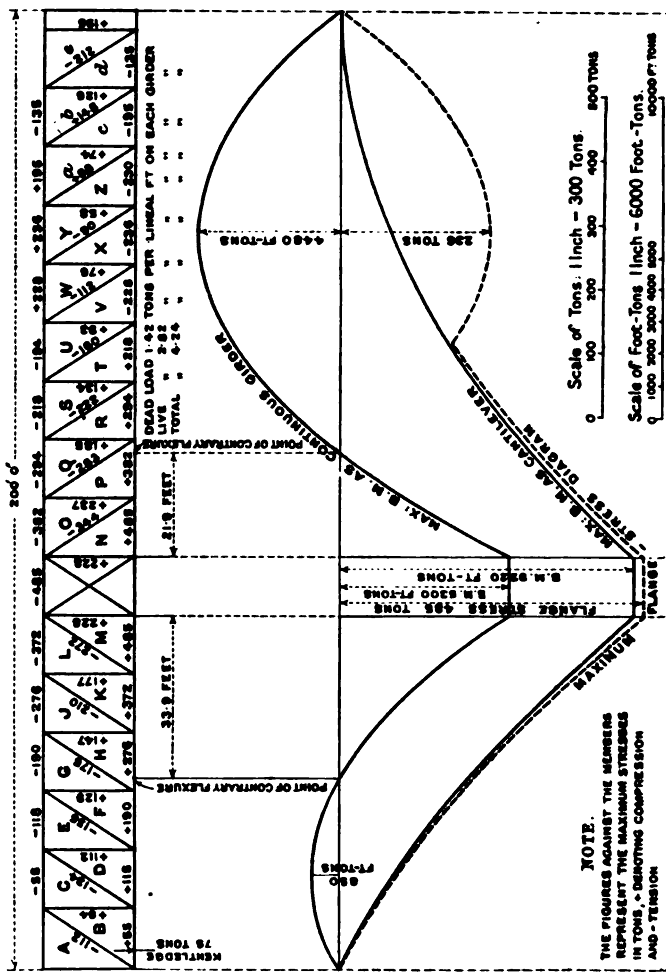
In calculating the stresses in the girders, the rolling load on the railway was assumed to be a string of heavy goods-locomotives, equal to 1·66 ton per lineal foot on each pair of rails with a maximum load of 18 tons on an axle. The live load on the roadways was assumed to be 1·5 cwt. per square foot, and the roadway cross girders were designed to carry two steam-rollers, weighing 20 tons each, passing one another.

The total length of the swing-span is 202 feet 6 inches, the radius of the nose end being 121 feet 6 inches, and that of the rear end 81 feet. The two main girders are 27 feet 9 inches apart between centres, and are divided into bays of 12 feet 3 inches, with a single system of triangulation, counter-braced at the bay over the centre pivot, the other diagonals being arranged so that they are in tension when the bridge is swinging.

The depth of the girders is 19 feet between main angles, the ratio of length to depth being 10·5 to 1. They were built with a rise from the centre pivot towards the two ends, the total rise at the nose end being 2 inches, and that at the rear end 1½ inch, in order to ensure the ends not deflecting below the horizontal while swinging. The booms are of Ụ section, the main angles being

5 inches by $3\frac{1}{2}$ inches by $\frac{5}{8}$ inch, the stringer-plates 1 foot 8 inches by $\frac{1}{2}$ inch, and the flange-plates 2 feet 6 inches wide, their total thickness at the centre being $3\frac{1}{2}$ inches.

Figs. 4 and 4*a* give the bending-moment and shearing-stress dia-



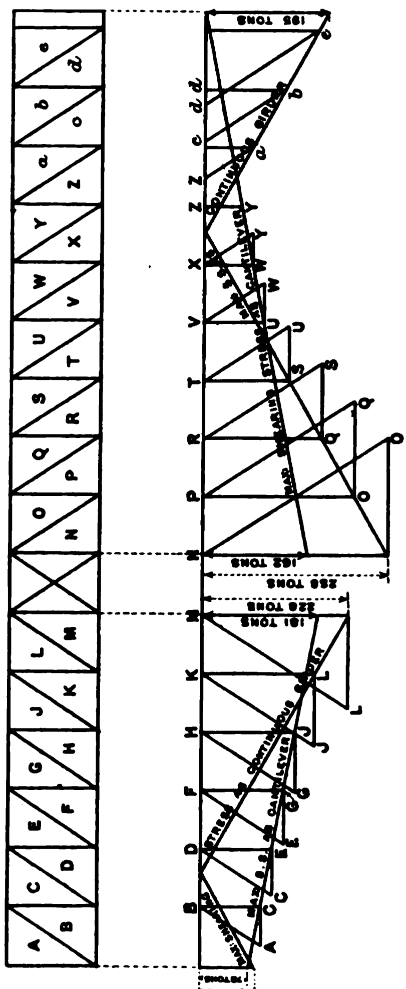
Figs. 4.

grams for the main girders, both when swinging, in which case they are considered to carry only the dead weight of the bridge, and also when at work as a continuous girder and loaded with the maximum live load throughout in addition to the dead load. There is also a

curve which shows the maximum flange-stress which can occur at any point under either condition of loading.

The lower deck carries a double line of railway. The cross girders are 26 feet long, 2 feet deep at the centre and 15 inches at

Figs. 4a.



the ends, and rest on the boom-angles of the main girders. They are connected to the vertical members of the main girders by means of brackets, the plates of which pass through the top flange of the cross girder and are riveted to the web. The rail-bearers are 12 feet

3 inches long and 15 inches deep, with a $\frac{3}{8}$-inch web and 4-inch by 4-inch by $\frac{1}{2}$-inch angles for flanges. This deck is plated with $\frac{5}{16}$-inch flat steel plates, 3 feet wide, laid transversely and connected together by steel tee-bars which act as butt-straps and stiffeners. The permanent way consists of 87-lb. flat-footed rails laid on longitudinal jarrah sleepers, 14 inches wide and 5 inches deep.

The roadway cross girders are 2 feet deep, the top flange being level with the top of the main girders. They are carried by large brackets which are connected to the vertical members of the main girders and which also serve the purpose of stiffening the bridge. The headway from rail-level to the underside of the roadway cross girders is 14 feet 6 inches.

The roadway is 20 feet wide and is carried on buckled plates 5 feet 9 inches by 3 feet 4 inches and $\frac{5}{16}$ inch thick, buckled upwards to the extent of 3 inches at the centre. These plates are carried by longitudinal bearers 12 inches deep, and transverse trimmers consisting of bulb-tees 7 inches deep. There are two footpaths 5 feet 6 inches wide, carried on $\frac{3}{16}$-inch corrugated steel plate.

The surface of the roadway on the swing-span is made with creosoted prismatic oak sets, 4 inches deep, laid on coke-breeze concrete with a layer of Callender bitumen sheeting between the concrete and the sets. On the approaches the roadway is laid in the same way, except that $\frac{3}{4}$ inch of rock-asphalt is substituted for the bitumen sheeting under the wood blocks. The coke-breeze concrete is made in the proportions of 3 parts of coke-breeze, 1 part of Bideford sand, and 1 part of Portland cement, and weighs about 100 lbs. per cubic foot.

The rivets are $\frac{7}{8}$ inch in diameter throughout the work, except in the rail-bearers, floor-plates, and a few other places where the plates are thin, in which cases the rivets are $\frac{5}{8}$ inch or $\frac{3}{4}$ inch in diameter. For the riveting done at the works hydraulic riveters were used as far as possible, the remaining rivets being put in with the Boyer pneumatic-hammer riveter, which was also used for nearly all the work done on the site, very few rivets being put in by hand.

The kentledge, of which there is about 156 tons, is placed in the last bay at the rear end of the bridge, underneath both roadway and railway floor-plates, and also in the boxes at the rear end of the main girders. It consists of cast-iron slabs laid transversely between the bottom flanges of heavy longitudinal girders, the space between these slabs and the floor-plates being filled with concrete made of scrap-iron and cement.

Span No. 3 on the north approach carries the road and railway from the north pier to the Towpath pier and is of similar construc-

tion to the swing-span, except that the main girders are farther apart, the distance between their centres being 37 feet 9 inches. This extra width is required on the railway floor as the rails are on a curve, and it also enables the roadway on the approach to be made 25 feet wide. The total length of this span is 75 feet 9 inches, and the north ends of the main girders are specially stiffened so as to support the south ends of the girders of span No. 2, which carries the roadway only from the Towpath pier to the masonry abutment No. 2. These girders are 103 feet long, 7 feet 6 inches deep, and 2 feet 6 inches wide, with double plate-webs 1 foot 9 inches apart. The ratio of length to depth in these girders is about 14 to 1, which is not the most economical ratio, but was adopted for the sake of appearance, the idea being to keep the top of the parapet at a uniform level throughout the bridge. The roadway is 25 feet wide, with a footpath 5 feet wide on each side, and is carried on trough flooring, laid longitudinally, supported by cross girders 36 feet long, 2 feet 3 inches deep at the centre, and 10 feet apart from centre to centre. Similar trough flooring is used on the south approach-span.

Expansion-bearings are provided at the north ends of spans Nos. 2 and 3, consisting of cast-iron bearing-plates attached to the bottom booms and free to slide on steel castings attached to the bed-stones, the lower castings being provided with gun-metal bearing-strips on the upper surface.

Span No. 1, which carries the roadway over a railway-siding between abutments Nos. 1 and 2, has a clear span of 28 feet only, and is made with square trough flooring 19 inches deep and of 12-inch pitch, laid longitudinally and provided with light parapet-girders on each side (Figs. 2, Plate 4).

As the turn-table of the bridge is below the level of high water at equinoctial spring-tides, it was necessary to put a water-tight casing round the top of the centre pier to prevent damage by flooding. This casing is of steel plates $\frac{3}{8}$ inch thick, and is carried on steel brackets fixed to the masonry (Figs. 6, Plate 4). It is made water-tight on the bottom by means of a layer of fine concrete 4 inches thick. Valves are provided in the bottom of the casing, so that any rain-water which collects in it may be let out.

Turn-Table (Figs. 5 and 6, Plate 4).

The lower roller-path is of cast steel, 30 feet 3 inches in diameter on the centre line of the rollers, and 2 feet wide on the upper surface. It is divided into twelve sections, the joints making an angle of 15° with the radius, in order to avoid uneven wear. The upper

and lower surfaces, and also the ends of each section, are machined. The sections are connected together by four 1½-inch turned steel bolts and also a 2-inch cover-plate bolted on the underside of the path. The path is laid on a finely-dressed granite bed in which recesses had been cut for the cover-plates, and these recesses were subsequently grouted up, so that the cover-plates form a key to prevent the path from moving. The path is also held down by forty-eight 1½-inch cotter-bolts, and twenty-four 1½-inch lewis-bolts. The pressure on the granite bed-stones under the path will not exceed 4½ tons per square foot under any condition of loading.

A cast-steel rack of 6-inch pitch, into which work the two pinions for turning the bridge, is fixed to the outside of the path and connected thereto by means of 1¼-inch countersunk bolts 12 inches apart.

The rollers, thirty-four in number, are also of cast steel, 2 feet 6 inches in diameter on the centre-line and 2 feet long, and are turned to such a taper that the sides if produced would meet at the centre pivot. The axles are of steel and 3½ inches in diameter, passing through gun-metal bushes in the rollers; they have a longitudinal groove on the upper side of the whole length of the bearing, through which a ⅜-inch copper oil-tube passes; this tube is perforated along the top and the outer end is bent upwards to receive the oil. Spiral grooves are also provided on the gun-metal bushes for distributing the oil. The axles are 4 feet 8 inches long and the space between the outside of the roller-frame and the water-tight casing is sufficient to allow any axle to be removed in case of necessity.

The roller-frame consists of two rings, which carry the inner and outer carriages of the rollers, and are connected together by steel plates and cast-iron distance-pieces. The inner ring is connected by means of steel angles and flat bars to a cast-iron collar which is free to revolve on the centre pivot.

The carriages are of cast iron, and are carried on the inner and outer rings of the roller-frame. The carriage on the inner ring is provided with a split steel bush which seizes the axle and prevents it from turning, the roller being free to revolve on the axle. The adjustment of the roller is effected by means of nuts on the inner end of the axle. The weight on each roller when the bridge is swinging is about 29 tons, which is equal to 1·2 ton per lineal inch.

The upper roller-path is of cast steel, and is similar in construction to the lower path. It is bolted to the underside of the annular girder, which is connected by radial arms to an octagonal cast-iron collar free to revolve on the centre pivot.

The annular girder is 2 feet 6 inches deep and 3 feet wide, of box section, with diaphragms at intervals of 2 feet 9 inches. It is made very stiff, as its function is to distribute the weight of the bridge evenly over the rollers. The main angles are 6 inches by 4 inches by $\frac{9}{16}$ inch, the webs $\frac{1}{2}$ inch, and the flanges $\frac{5}{8}$ inch thick. The annular girder is bolted to the underside of each main girder by means of forty-six 1-inch turned steel bolts, and also to the cross girders and rail-bearers which pass over it. These rail-bearers and cross girders are made extra strong so as to give increased stiffness to the annular girder.

The centre pivot (Figs. 6) is of cast iron 2 inches thick, resting on a granite bed-stone into which it is dowelled, and is also held by eight $1\frac{3}{4}$-inch lewis-bolts. It has two bearings, to take the centre collars of the roller-frame and the annular girder respectively.

Method of Erection.

The swing-span was erected in its normal open position upon a timber staging consisting of the permanent jetties at the centre pier with an additional row of piles driven on the south side, the whole of the timber-work being braced together and decked over. The piles of this staging were so arranged that no pile would receive a load of more than 15 tons at any period of the erection of the steel-work. Access to the centre pier was obtained by means of a timber gantry from the south bank of the river, carrying temporary rails in continuation of the Great Western Railway approach-line. By this means all the steelwork of the turn-table and water-tight casing was conveyed to the site by rail, the girder-work itself being delivered by barges at the centre pier.

Before commencing to erect the turn-table, the casing of the centre pier was fixed and made water-tight. The turn-table (including its centre pivot, lower roller-path, rollers and roller-frame, upper roller-path, and annular girder) was then built up, each part being levelled and adjusted with the utmost care, and the whole being revolved and tested before any of the weight of the main girders was allowed to come upon it, in order to ensure each roller receiving an equal share of the weight of the bridge.

The centre portions of the bottom booms of the main girders, which had been riveted up on staging, were next placed on the annular girder and bolted down in their final positions, after which the entire lengths of the two bottom booms were laid down on blocks supported by the staging and adjusted to give the correct rise

towards the ends. The centre cross girders and rail-bearers were then placed in position and a temporary line for a travelling crane was laid down on them. The crane which ran on this road was used for erecting the remaining cross girders and rail-bearers, and also the vertical and diagonal members of the main girders: the whole of the work was erected from the centre both ways, and the top boom was bolted on as the work proceeded. For the erection of the roadway-girders and for riveting purposes, a travelling stage about 3 feet lower than the underside of the cross girders was built to run on rails on the railway-deck, and spanning the full width between the main girders. As soon as the roadway-girders had been erected, the travelling crane was dismantled and lifted on to the roadway, where it was used for the erection of the machinery-tower. During the whole of the erection the girders were supported on staging so that the whole structure was at rest when the riveting was done, which could not have been the case had the erection been carried out on the cantilever principle. The fixed span, No. 3, was erected in its correct position on timber frames resting on sills on the bank of the river. The main girders for span No. 2, which weigh about 50 tons each, were delivered on the site in three sections, and were erected and riveted on the ground-level, being afterwards raised into position by jacking and packing with timber. The girder-work for the north approach was conveyed from the works to the site by road.

The boilers, compressors, smiths' shop, etc., for the whole work were situated on the south bank of the river, the compressed air for riveting being conveyed by pipes over a gantry on to the centre pier, and under the bed of the river to the north side.

TURNING-MACHINERY.

The bridge is worked by hydraulic power derived from the Bristol Docks Committee's pumping-station, which supplies power for all their hydraulic machinery at the city docks.

The working-pressure is 750 lbs. per square inch, and the water is carried to the centre pier under the bed of the river in 2½-inch copper pipes, which are laid in duplicate to prevent stoppage in case of a burst pipe. The pipe is carried up the side of the centre pier and under the bottom roller-path. It then passes up through the centre pivot, at the top of which it has a swivel-joint, and is carried thence under the railway deck-plating and up one of the legs of the machinery-tower to the engines.

The turning-engines are three-throw reversible hydraulic engines with rams 4 inches in diameter and 14 inches stroke. Two engines are provided, the second being used only in case of a breakdown. These engines, by means of spur-pinions and wheels, drive two horizontal shafts, at the ends of which bevel-gearing drives vertical shafts placed at diagonally opposite corners of the tower. These shafts pass through bracket bearings attached to the legs of the tower, and also through bearings in steel boxes, which form part of the annular girder, and at their lower ends carry pinions 1 foot 11 inches in diameter on the pitch-circle, which engage with the circular rack on the bottom roller-path and thus turn the bridge (Figs. 5, 6 and 7). The reduction in speed from the crank-shaft to the horizontal shaft is in the ratio of 63 to 17, and that from the horizontal to the vertical shaft 38 to 13, giving a total reduction 10·7 to 1.

While the bridge is swinging, the whole weight is carried on the live ring, and when the bridge has been swung into position across the river the ends of the main girders are lifted slightly by means of four 60-ton hydraulic presses, one attached to each end of each main girder, acting against cast-iron bearing-blocks on the abutments. As soon as the girders have been lifted, sliding blocks are moved into position over the bearing-blocks and the presses are released, so that the sliding blocks then take the reactions at the abutments. The sliding blocks are moved in and out by means of hydraulic cylinders and rams, fitted with chains with a multiple of 2 to 1, placed in the bottom booms of the main girders and worked by a lever in the machinery-house (Fig. 8, Plate 4).

The cylinders of the lifting-presses are of cast steel lined with gun-metal, and have rams 16 inches in diameter, of cast iron cased with gun-metal. The working-stroke of the ram is $3\frac{1}{2}$ inches, but the actual amount that the girders are lifted is only $\frac{7}{8}$ inch at the nose end and $\frac{5}{8}$ inch at the rear end; $\frac{1}{4}$ inch of these amounts is allowed for clearance in moving the sliding blocks in and out, so that the permanent lift only amounts to $\frac{5}{8}$ inch at the nose end and $\frac{3}{8}$ inch at the rear end. The cut-off of the ram is arranged by means of lock-nuts on the piston-rod which engage with the top of the cylinder. The pressure-water is conveyed to the presses by means of pipes from the machinery-tower where the lever is situated. When the pressure is removed, the rams are overhauled by means of balance-weights attached by chains to the piston-rods and acting over sheaves.

An automatic locking-bolt worked by a spring is provided in the middle of each end of the swing-span. The bolt is 3 inches

by 4 inches in section and has a stroke of 5 inches. The spring keeps the bolt normally shot, but when the bridge is being closed the bolt is pressed back by striking the ramp of a steel rubbing-plate on the abutment, and when the bridge reaches its correct position the bolt is automatically shot into a cast-steel socket let into the masonry of the abutment. When it is required to open the bridge the bolt is withdrawn by means of a treadle-lever in the machinery-tower which actuates it by means of chains.

The time taken for the complete operation of opening or closing the bridge is about 2 minutes 15 seconds.

Navigation-Signals and Lights.

The navigation-lights provided for controlling the passage of ships through the bridge-way at night-time are arranged with a view to always swinging the bridge so that the nose end will point up-stream when open: the reverse direction is intended to be used only to prevent an accident in the event of a ship getting out of control when going down-stream and approaching too near to the bridge to allow it to be swung up-stream. The lights provided are:

(i) A red light showing all round, fixed on the centre of the swing-span immediately above the machinery-tower. This light is provided with screens so that the red light can be obscured through arcs of 180° on either the up-stream or the down-stream side when the bridge is open.

(ii) Two green lights fixed one at each end of the down-stream girder of the swing-span above the level of the handrail to the roadway. Each of these lights is permanently masked through an arc of 90° as shown in Figs. 2.

(iii) Two green lights, one on each of the pilasters of the north pier. These lights are each masked through an arc of 90° on the north side, so that they are visible from the river, but not from the north approach-road.

When the bridge is open for ships to pass through, the red light at the centre can be obscured on either the up- or the down-stream side, and this is the signal for ships to approach from that side. The illuminant for these lights is oil.

During the day-time the signalling is carried out by means of two cones hoisted on a flag-staff on the machinery-house; of these cones one is a north cone (point upwards) and the other a south cone (point downwards). When the bridge-way is closed for navigation, both cones are hoisted, and when the bridge is opened, the north cone is lowered as a signal that vessels may pass down-stream, or the

south cone is lowered as a signal that vessels may pass up-stream. The two cones are never lowered simultaneously, as vessels are not allowed to pass each other in the bridge-way. The yard on which the cones are hoisted is fixed so that it points across the river when the bridge is open, and up- and down-stream when the bridge is closed to vessels. This ensures both cones being visible from the river when the bridge is open.

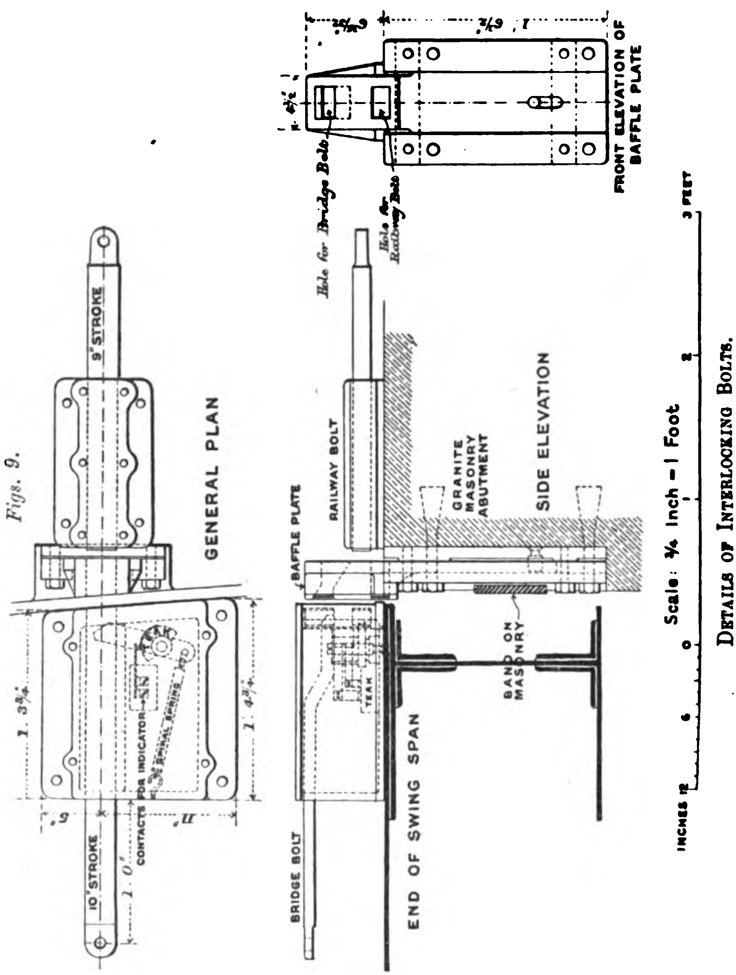
The bridge-master is in telephonic communication with two stations each about $\frac{1}{4}$ mile distant, one above and the other below the bridge, and from these stations he receives warnings at night or in foggy weather of the approach of vessels.

Interlocking and Indicating.—The levers for working the machinery are interlocked with the railway-signals so that the bridge cannot be opened until the railway-signals are set against the trains, and the catch-points are open on each side of the bridge. This is effected by means of two pairs of interlocking bolts (*Figs. 9*), one pair being situated at each end of the bridge on the railway-deck level. One bolt of each pair is on the bridge, and is worked from the machinery-tower, and the other, which is on the abutment, is worked from the railway signal-cabin. Assuming the bridge to be set for railway-traffic, both bolts are shot, and the bridge bolt cannot be withdrawn until the railway bolt has been withdrawn. Conversely, when the bridge bolt has been withdrawn, the railway bolt cannot be shot again, as a baffle-plate is moved in front of it and remains there until the bridge bolt is again shot.

When the bridge-master wishes to swing the bridge for river-traffic, he rings, from the machinery-tower, a bell in each of the railway signal-cabins, and as soon as the signalmen have withdrawn their bolts he receives a reply signal. The withdrawal of the railway bolts mechanically releases the lever by which the bridge bolts are actuated, and he withdraws these bolts. This movement back locks the railway bolts and electrically releases the lifting-press lever, which he then pushes over; and as soon as the ends of the bridge are lifted correctly, the sliding-block lever is electrically fixed. When the sliding blocks are properly withdrawn, the ends of the bridge can be lowered, and the action of lowering frees the starting-valve handle, enabling the bridge to be swung open. When the bridge has been turned to its open position, one of the screens can be raised by means of a lever to obscure the red light for one direction only.

In order to close the bridge the screen must first be lowered so that the red light is again shown; then the bridge is turned to the railway position and the shooting of the automatic locking-bolts electrically frees the lifting-press lever; this lever is then pushed over, and the

lifting of the ends of the bridge frees the sliding-block lever; the sliding blocks are then inserted and the lifting-press lever is pulled over to lower the ends of the bridge; this electrically releases the interlocking-bolt lever which is moved over, thus electrically locking



Figs. 9.

DETAILS OF INTERLOCKING BOLTS.

the turning, sliding-block, and lifting-press levers, and mechanically releasing the railway bolts, which being shot put an electric lock on the interlocking lever.

Electric indicators fixed in the machinery-tower give the following information to the bridge-master.

1. Railway bolt: shot or withdrawn.
2. Lifting-presses: up or down.
3. Sliding blocks: in or out.
4. Automatic locking-bolt: shot or withdrawn.
5. Bridge set for road or river.

Of the first four indicators, there are two sets, one for the nose end and the other for the rear end.

The drawings for the work were prepared by the late Mr. J. M. McCurrich, M. Inst. C.E., Engineer of the Bristol Docks, and the work was carried out by his successor, Mr. W. W. Squire, M. Inst. C.E., the Author acting as Resident Engineer. The Author wishes to express his thanks to Mr. T. B. Cooper, B.Sc., Assoc. M. Inst. C.E., for assistance in preparing that portion of the Paper which refers to the foundations.

The Paper is accompanied by five drawings and two tracings, from which Plate 4 and the Figures in the text have been prepared; also by three photographs.

[APPENDIX.

APPENDIX.

Table of Weights of Swing-Span.

	Tons.	Tons.
Steelwork in main girders	231	
Steelwork in longitudinal and cross girders, deck plating, etc.	234	
Steel and cast iron in handrailing	21	
Steelwork in machinery-tower	42	
Cast iron and cast steel in curbs to footpaths	12	
Steelwork in annular girder	35	
Steel and cast iron in roller-frame	14	
Cast steel in rollers	51	
Oak blocks, concrete, asphalt, etc., in footpaths and roadway	99	
Permanent way	18	
Turning-machinery, pipes, etc.	36	
Timberwork, etc., in machinery-house	12	
Kentledge	156	
Cast steel in top roller-path	29	
Total weight of swinging parts	—	990
Cast steel in bottom roller-path	52½	
Cast iron in centre pivot	2¾	
Weight of fixed part of turn-table	—	55¼
Total		1,045¼

Steelwork in Approaches.

Fixed Span No. 1:	Main girders	9½	
	Trough flooring	37½	
		—	47
Fixed Span No. 2:	Main girders	102	
	Cross girders and trough flooring	102	
		—	204
Fixed Span No. 3:	Main girders	87	
	Cross girders, floor-plating, etc.	136	
		—	223
South Approach:	Main girder, cross girders and trough flooring	116	
		—	116
	Total steelwork in approaches		590 tons.

Discussion.

The PRESIDENT, in proposing a vote of thanks to the Authors, observed that the Papers described in detail the design and construction of what he believed were two of the largest swing-bridges in the world, and contained a great deal of information which would be of value to The Institution. The President.

Mr. C. O. BURGE, who represented Mr. Allan in his absence in Australia, thought there was one point which might be explained before the discussion began. Some members might have been surprised to see that such a structure as the Pyrmont swing-bridge, a substantial work in one of the great cities of the Empire, should be flanked on each side by a row of timber spans, which gave it a temporary and inferior appearance. The design involving the timber spans had been agreed upon in opposition to the opinion of the engineers on the spot. The Engineer-in-Chief had been very anxious to have a bridge entirely of steel, but the decision had rested with the Committee of Public Works, who were Members of Parliament, but none of them engineers. There was, however, something to be said for construction in timber, because New South Wales timber was of a very high quality. The strength of the ironbark used for the timber spans was nearly one-half of that of wrought-iron: it could withstand a tension of 10 tons and a compression of 4½ tons per square inch, and its density was so high that it weighed about 80 lbs. per cubic foot. In the form of piles or girders ironbark had generally a life of 30 to 35 years; and it had been thought that the saving by constructing a large part of the bridge of timber was worth effecting, because at compound interest it would provide more than a sufficient sum after 30 years to renew the bridge in steel. The Railway Construction Department, with which he himself had had to do, had built a large number of viaducts of timber on the basis—arrived at by careful calculation—that if a bridge could be built in timber for less than one-half of the cost of a steel bridge it was better, economically, to build it so; but those bridges were up in the bush and not, like the bridge under consideration, in the heart of Sydney. It seemed to him that it would have been worth while for a rich Government like that of New South Wales to build a steel bridge throughout, even though the latter would have cost a little more. Mr. Burge then exhibited a series of lantern-slides illustrating the Pyrmont bridge and its construction. Mr. Burge.

Mr. Savile. Mr. SAVILE wished to mention a few things which he had not been able to put into the Paper, as the bridge had not been actually opened until 2 or 3 days after the Paper was sent in. From the 4th October, when the bridge was opened, to the 31st January, it was worked on 222 tides and was swung 1,048 times for the passage of 2,411 vessels, the average being 4·72 swingings per tide, and the average interruption of traffic being 6½ minutes. The time of the swinging was given in the Paper as 2¼ minutes, but since the bridge had been working and the driver had become more experienced, the speed had been improved, and in the previous week the time taken had been reduced to 1 minute 45 seconds for the opening and 2 minutes 5 seconds for the closing. One interesting point had cropped up in connection with the automatic locking-bolts, of which there was one at each end. One morning in March of the current year, after a sharp frost at night and a warm sun in the morning, the east girder became warmed while the west girder was still practically frozen, with the result that the bridge bent slightly, and when at 11 o'clock it was desired to open the bridge, it was found impossible to withdraw the locking-bolts without the assistance of a jack, causing a delay of about 20 minutes. That delay might have been serious if a tug had been approaching towing a string of vessels, as tugs often did. One method of getting over the difficulty might have been to enlarge the socket for the bolt. There was a clearance of a bare ⅛ inch in the socket. The objection to enlarging the socket, however, was that, under present circumstances, if the bridge was going at all too fast when it got into position, the bolt, instead of shooting, rode over the hole, and in that way saved the bridge from the severe jar it might suffer if the bolt shot when the bridge was swinging too fast. It had not been considered safe to enlarge the socket, and therefore the tail-end locking-bolt had been withdrawn altogether, and the bridge was worked only with the locking-bolt at the nose end. The tail-end locking-bolt was still kept on the bridge, but it was made so that at the end of the stroke it was not far enough out to get into the socket. The bolt was not removed entirely, because its removal would have necessitated considerable alterations in the electric contracts for indicating and interlocking. He would be interested to hear whether anyone else had had experience of the twisting of a bridge due to the sun. The Bristol bridge was particularly subject to lateral bending, because the upper roadway-deck completely protected one girder from the sun, while the other girder was much exposed, whereas in the ordinary type of bridge the sun was generally on both girders, even if one was partially protected. The amount of water used for one complete opening and shutting of the bridge was 182

gallons, which included the water used in the presses, and in the rams for sliding in the blocks. Since the working of the bridge was started, an indicator had been added in the machinery-tower to show the driver at any time the position of the bridge. As stated in the Paper, there was originally only an indicator showing the driver when he was over a dolphin and when he was in position, so that he did not know where he was until the indicator suddenly showed "open" or "shut." In foggy weather the man might swing the bridge a little too far and get the tail-end of the bridge over the stream and liable to be fouled. The only accident that had occurred to the bridge in working was that one of the rams used for lifting the ends of the girder dropped while the bridge was swinging and came in contact with the cast-iron block on the abutment. Originally, when the man was swinging the bridge the lever which operated the presses was always half-way between pressure and exhaust, but on that occasion there was a little leak, so that the pressure-water got into the cylinder and let the ram down so that it fouled the block on the abutment. That had been prevented from happening in the future by altering the electric contacts of the lever, so that when the lever was not at "pressure" it was at "exhaust," and therefore water could not get into the cylinders during the operation of swinging. Mr. Savile exhibited a series of slides illustrating the Bristol bridge and its construction. Mr. Savile.

Mr. C. O. Burge wished to ask a question with regard to the time required for moving the swing-bridge over the River Avon. It appeared from the Paper that it had been reduced to 1 minute 45 seconds, the motive power being hydraulic. In the Paper on the Pyrmont bridge it was stated that the minimum time of moving the bridge was 30 seconds, the motive power in that case being electricity. In the Pyrmont bridge the total weight of the swing-span was 850 tons, and in the other bridge 990 tons. The difference in weight would account for some of the difference; but still, there seemed to be a large difference between the times occupied in moving the two bridges to the full extent. The Pyrmont bridge swung about 80 degrees, and according to Figs. 2, Plate 4, the Bristol bridge appeared to swing through much the same range. It would be interesting to know why there was so considerable a difference, because in a navigable river, especially at Bristol, where the bridge had to be crossed by railway-trains, it was very important that the least possible time should be occupied in the operation. Mr. Burge.

Mr. W. H. Thorpe observed that the two Papers naturally raised the old question of swing-bridges having equal arms versus swing-bridges having unequal arms. He did not pretend to say that Mr. Thorpe.

Mr. Thorpe in the case of the Bristol bridge any other than unequal arms could have been adopted; but it appeared to him that, wherever practicable, the arrangement of equal arms was better. In the case of a bridge having unequal arms, the turning-moment necessary to rotate the long arm of the bridge was greater than the turning-moment necessary to move the short arm, for the same angular acceleration at starting; and there was a slight tendency for the bridge to move about some centre other than the pivot. It brought side pressure—slight in the present case—on the pivot, which might readily be avoided by adopting equal arms. More important, however, was the question of the effect of wind upon the longer arm, an effect which might considerably increase the amount of power necessary to open the bridge. The cost of a bridge with unequal arms was perhaps a little less; but that depended on the price of the kentledge as against the price of the girder-work. The Bristol bridge had been perhaps cheaper as built; but it was possible that had both arms been made of the length of the longer, by shortening the side-walls and flooring to the road, and cutting out some of the piling, there might have been a slight saving, although it was somewhat doubtful. In one particular case within his knowledge on the Manchester Ship-Canal—the Barton swing-aqueduct—it was originally proposed to make clear-openings of 90 feet and 60 feet respectively; but when the preparation of the working-drawings was gone into it was found that, having regard to the contract price for girder-work and the contract price for kentledge, it was decidedly cheaper to make the arms of equal length, and they were so made; not, however, wholly for that reason. In the case of an aqueduct having a trough carrying 760 tons of water, the bridge, although it might be properly balanced with the trough full, would be very badly out of balance when, by accident or for repair, the water was run off. The long end would be on the point of tilting up. That, of course, had settled the matter at Barton: the arms there had to be of equal length. He noticed that at the Pyrmont bridge there had been some difficulty with the roller-path, and he thought that was not very surprising. The construction and correct fixing of a roller-path and rollers were really matters of rather high art and special experience, and without the resources of large and well-equipped machine-shops, it was not remarkable that there should have been some little trouble.

Mr. Homfray. Mr. S. G. Homfray observed that the Pyrmont bridge was interesting not only as showing what was being done in a very distant part of the Empire, but also because some novelties were introduced in it—apart from the timber spans. The Bristol bridge

also was of great interest, as although there was one other double-decked bridge in England—that over the Stanley Dock entrance at Liverpool—it was not nearly as large as the Bristol bridge, which marked a departure in swing-bridge construction. He believed that in America there was at least one double-decked swing-bridge, but he had not been able to find a reference to it, and the fact did not render the Bristol bridge less interesting. With regard to the Bristol bridge being the heaviest swing-bridge, although bridges of considerably greater swinging weight had been built in England, no bridge had been built in which the weight on the rollers was so great. It might be interesting if he mentioned a few of the heavier bridges in this country, going back first to a bridge which, although rather lighter than the Bristol bridge, was still of great interest for many reasons, namely, that at Goole on the main line of the North Eastern Railway, between Doncaster and Hull. That bridge, built about the year 1868, was the pattern on which practically all live-roller swing-bridges had been built. It was interesting also from the fact that a Past-President of The Institution (then Sir W. G. Armstrong) was largely responsible for the design and carrying out of the work, which was done under his direction.[1] The length of that bridge over-all was 250 feet, and its swinging weight 750 tons. That weight was not exceeded in other bridges of similar design—notably the Naburn bridge on the North Eastern Railway, between Selby and York—until 1876, when the swing-bridge over the River Tyne was completed, the total length of which was 280 feet and the swinging weight 1,400 tons, 870 tons of which was carried upon a centre press forming a hydraulic pivot which relieved the weight on the rollers. Mr. F. N. Thorowgood, M. Inst. C.E., was responsible for the foundations of that bridge. Then, in 1894 eight swing-bridges over the Manchester Ship-Canal were built, four of which were well over 1,000 tons in weight. The Trafford Road swing-bridge had a total length of 212 feet and a swinging weight of 1,600 tons, with a centre relieving-press of 800 tons capacity; and, as far as he knew, it was the heaviest road-bridge that had been built. The Barton Aqueduct swing-bridge had a total length of 234 feet with a swinging weight of 1,600 tons, including the water in the trough. That bridge had also a centre relieving-press of 800 tons capacity. The Latchford and Stockton Heath swing-bridges were similar, Mr. Homfray.

[1] Sir W. G. Armstrong, "Description of the Hydraulic Swing-Bridge for the North Eastern Railway over the River Ouse, near Goole." Proceedings of the Institution of Mechanical Engineers, 1869, p. 121.

Mr. Homfray. having a total length of 252 feet and a swinging weight of 1,200 tons each, the centre press taking off 600 tons in each case. There were four other bridges on the Ship-Canal ranging between 125 feet and 238 feet in length and weighing about 800 tons. Those were the largest and heaviest bridges that had been built in England, as although the Hawarden bridge had a length of 287 feet its swinging weight was rather under 657 tons. All those bridges, with the exception of the Goole bridge, he knew well, as he had been personally concerned in their erection and control. It would therefore be seen that in no case had a swinging weight of more than 1,000 tons on the rollers been exceeded. That gave, as stated in Mr. Savile's Paper, a load of about 1·2 ton per lineal inch of roller, which was exactly the same as that on the Pyrmont bridge; but whereas in the Bristol bridge the rollers were 2 feet 6 inches in diameter, in the Pyrmont bridge they could not be much more than 15 inches, which might prove rather a serious matter hereafter. All the bridges he had mentioned were worked by hydraulic power, and on the same lines. Whether the hydraulic turning-machinery was placed on the pier, or in a house raised above the bridge, did not affect the question. At the Pyrmont bridge electrical power was used both for the turning and for the end gears. He thought it very necessary that such bridges, some of which were on tidal rivers where it was a serious thing to stop the traffic, should be always ready for work; and one of the best ways of ensuring that was to have the working parts as few and the speeds of the principal parts as low as possible. That conduced to reduction of wear and to long life. The Goole bridge had had very little done to it, and was still as it was originally designed; the Tyne bridge had been at work for 31 years with no renewals whatever, and with a minimum of repairs, and was now doing a great deal more work than it was expected ever to do when it was built—facts which said something for that class of installation. In 1905 the Tyne bridge was opened 4,295 times, an average of nearly six openings per tide. With electrical machinery directly operating the different motions, as in the Pyrmont bridge, there was a high motor-speed, a considerable amount of reduction-gearing, and, in the case of the gear at the ends, long shafts running from end to end with gearing and cams and a certain amount of complication in the way of cam cut-offs, switches, and safety-gears. The question whether that was the best arrangement must be decided for each case according to its particular circumstances. But even where electricity was available, he ventured to think it was worth consideration whether the transmission between the electric motor

and the point of application of the power on the bridge, especially the end blocking-gears, should be through shafts and gearing or through the medium of a pump and a hydraulic pipe. He was no specialist for hydraulic machinery, but as it was the older he naturally knew more about it than he knew about electrical machinery. On the Bristol bridge the total reduction between the hydraulic engines turning the bridge and the rack was 203 to 1, whereas on the Pyrmont bridge it was 1,223 to 1, or six times as much; that was to say, there was six times as much gear. It was a question on which side the balance of advantage lay. Mr. Thorpe had referred to the Bristol bridge being unequal-ended, and had asked where the economy of that came in. Mr. Homfray thought it might be taken roughly that the economy ceased when ordinary kentledge had to be abandoned for ballast, and special ballast had to be adopted, particularly if it were lead. The ballast must be near the end. The plating-up necessary for the ballast-box at the tail end gave more wind-surface, and he thought that, if the effect was worked out, in most cases it would be found there was not much difference between the two ends in the matter of wind-pressure. With regard to the difference between the cam-gear at the ends of the Pyrmont bridge and the solid blocks at the end of the Bristol bridge, there was the question of efficient bearing-surface—not only for carrying the weight, but also for wear and tear—and there was also the question of time. As to Mr. Burge's comparison of the time for swinging the two bridges, he thought it was clear from Mr. Allan's Paper that the 30 seconds was the fastest time ever attained for swinging the Pyrmont bridge only, while $1\frac{3}{4}$ minute for the Bristol bridge was the time of ordinary working, and included lifting and unblocking the ends and getting ready to swing. On the Tyne bridge 30 years ago a speed was obtained which only stopped the traffic over the bridge for $2\frac{1}{2}$ minutes, in which time the bridge was unblocked and swung open, a tug and a vessel were passed, the bridge was closed again, and traffic over it was resumed. That was an exceptional performance, but 3 minutes was a very common time. No doubt the fact that the bridge was equal-ended and that the vessel was closely followed up helped towards this result. It was the slowness of the vessel that prevented the performance of the operation in the minimum time in all cases. Mr. Homfray.

Mr. G. E. W. Cruttwell thought Mr. Allan was to be congratulated on having no idle rollers on the roller-path, as it was very difficult to make them exactly true, so as to take their proper share of the load. Even if they were adjusted to take their share of the load when the Mr. Cruttwell.

Mr. Cruttwell. traffic was passing over the bridge, there was a tendency, when the bridge was swinging, for the deflection of the girders, when they were unsupported at the ends, to alter the adjustment of the upper roller-path to a trifling extent, unless it was extremely rigid. The least displacement of the position of the roller-path would make some of the rollers take more of the load and others less than they did when the bridge was carrying the traffic. That was one reason why, wherever practicable, it was desirable to adopt the central lift instead of the ring of rollers. Neither at Pyrmont nor at Bristol was that possible, because there was no solid foundation for the roller-path at the rear end of the bridge, which was necessary with the central lift, the rear end having a preponderance given to it in order that it might always bear upon the roller-path at the end. With that system the preponderance need be only a few tons, and it was only necessary to have a couple of rollers, one on each side of the rear end, to take that preponderance, as compared with sixty-six rollers in the case of the Pyrmont bridge and thirty-four at the Bristol bridge. Radial rollers were expensive to make and difficult to adjust, and he thought it would be found that a central lift, where it could be adopted, was much simpler and more economical in every way, especially for a swing-bridge over a lock-entrance or passage, where it was possible to place a roller-path at the rear end on the quay-side. He did not understand the object of the 6-inch layer of sand which had been spread over the bottom of the Sydney pier. He thought it would have been much better to lay the concrete of the pier directly on the bottom, whatever it might have been, rather than to interpose the layer of sand. Even if there were a little silt in the trench he thought it would make a better mixture with the concrete than with the sand. With regard to conveying the cables across to the central pier of the Pyrmont bridge the Paper stated that they were laid 30 feet below low-water mark, which he made out would be about 7 feet below the bottom of the harbour. He would like to know whether that was deep enough to guard against any damage from vessels' anchors and to allow for future dredging. In the case of the Bristol bridge, perhaps the Author could say whether the hydraulic pipes which crossed the Avon to the central pier were protected in any way from similar damage. The bitumen sheeting which was laid between the concrete and the pavement of the roadway on the Bristol bridge had also been used at the Tower bridge, but the result had not been satisfactory. Recently some of it had been taken up, and had been found to be quite rotten and porous; in fact, it was owing to its letting water through that it had had to be taken up. It was now being replaced with a composition of pitch. With regard to

the jamming of the locking-bolts of the Bristol bridge due to the curvature of the girders, a similar curvature had occurred in the case of the girders of the temporary foot-bridges which were placed on either side of London Bridge whilst it was being widened. The foot-bridges were roofed over, so that the sun could only get to one side at a time, and the girders being quite close to the parapet of the bridge it was very easy to take extremely accurate offsets to them. It was noticed for a long time that the girders deflected sideways, so much so, that it was possible to see their deflection. Measurements showed that every day when the sun was shining in the morning the girders deflected towards the east, and in the afternoon, when the sun was in the west, they deflected towards the west. The deflection took place at the middle of the girders, the ends being fixed. The amount of movement was between 1 inch and 2 inches. It seemed that if the locking-bolts at the Bristol bridge, instead of being made rectangular as described, had been made conical, like the point of a pencil, very likely they would not have got jammed in the same way; but he would like to hear Mr. Savile's opinion on that point. Mr. Cruttwell.

Mr. F. N. Thorowgood observed that as Mr. Homfray had mentioned the sinking of the foundations of the Tyne swing-bridge, with which he too had been connected, he would like to draw attention to the fact that the cylinders which carried the piers of that bridge, which were taken down almost to rock—or at least very hard material—were sunk under compressed air by a system which was not generally used. There were two valves opening downwards. Entrance was through the first valve, which was in the cylinder below the level of high water, and then through the lower valve. At the time, 32 years ago, many engineers said that was a dangerous method. The usual plan was to have the air-lock at the top of the cylinders, but in the case he mentioned the air-lock was like the old shot-flask, one valve closing and the other opening in the cylinder itself. No accidents occurred, but once he was going down with a man, and when the first door was closed, before the balance of pressure could be restored to open the lower door, the man fainted. Mr. Thorowgood.

Mr. W. C. Copperthwaite asked how it was that, in the Bristol bridge, a departure had been made from the general practice with regard to swing-bridges in England, especially those carried out by the Armstrong firm, in which the live-load rollers were carried on radial axles attached to a ring which went round a pivot in the centre—as in the case of the Goole, Naburn, and Selby bridges. At the Bristol bridge there was an extremely rigid frame with two circular girders at the outside, and the rollers were fitted between Mr. Copperthwaite.

Mr. Copperthwaite. the girders. He did not see that there was any economy in that construction, and, as one who had to look after that kind of work, he could see that there would be great difficulty in getting at the rollers, and at the work generally, on account of this extra material. He would like to know why that practice, which, as Mr. Homfray had said, had been very successful in the other bridges, had been departed from. Another point he noticed was that the screen put round to keep the roller-path dry at high spring-tides was of wrought iron. At the Selby swing-bridge a similar sheath was fitted which was of cast iron, it having been considered that if a vessel struck the screen it would probably break one or two panels of cast metal which could be replaced by reserve panels before the next high tide. If, however, a boat struck a wrought-iron fender, that fender would crumple up: it might or might not foul the working-gear; but at any rate it was not a matter that could be put right on a single tide. Many days would pass before the bent plates could be cut out and replaced. Another matter on which information was required was in regard to the 1·2 ton per inch of width of rollers. In English practice it was generally 1 ton per inch. American practice, however, worked out at 1·7 ton per inch on a 30-inch roller, and the Bristol bridge was well inside that limit. He had been carrying out for the Chief Engineer to the London County Council a small swing-bridge, of which he had put a plan on the wall, called the Old Gravel Lane bridge. The Chief Engineer had suggested that as the bridge was, so to speak, of a manageable size, an endeavour should be made to ascertain what the real drawbar-pull was for a bridge of that kind. By drawbar-pull he did not mean the pull necessary at the particular place where the rack happened to be fixed, but the actual pull if taken at the centre of the roller-path itself. Many experiments had been carried out. First an attempt was made to find what the coefficient would be of a roller-path without the weight of the bridge upon it—with nothing but the rollers, the upper roller-path, and the circular plate which was used to join it together, the total weight of which was about 129 tons. When the bridge was erected the pull was taken at the nose, at the point marked B (*Fig. 1*), and again just outside the roller-path; and adjusting the calculations, allowing for leverage and so on, figures were obtained which were fairly close together for the different trials. With an unloaded roller-path the pull was practically 1·16 per cent. of the weight, that was, the coefficient would be 0·012. The unloaded-path coefficient was obtained with a velocity of about 19 feet per second, which was considerably in excess of what the actual working-velocity would be.

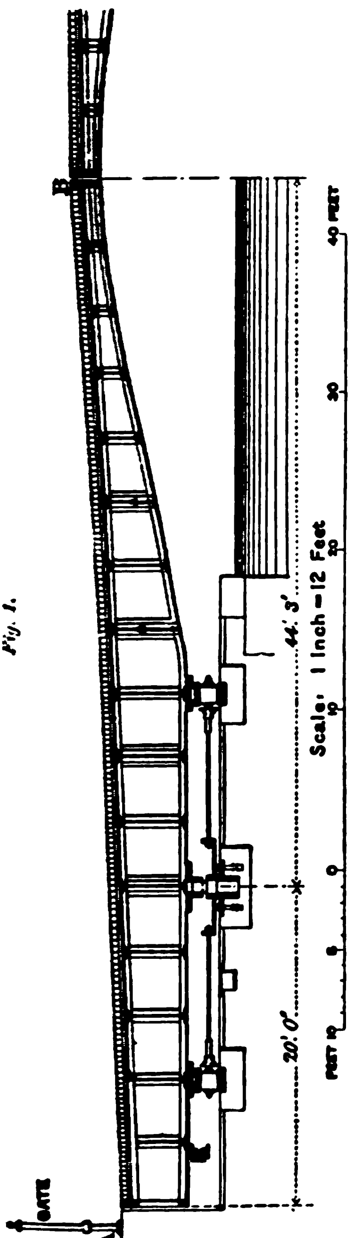


Fig. 1.

OLD GRAVEL LANE BRIDGE.

Mr. Copperthwaite.

When the bridge was constructed, with everything complete, it was found that the pull varied between 1·8 per cent. and 2·2 per cent. or a coefficient of 0·02. When the roller-path was moving at 3 feet per minute the nose was moving between 11 and 12 feet per minute, which was rather less than half the speed of ordinary working. It practically came to the fact that the force required for swinging an ordinary bridge of that character was obtained by multiplying the weight of the moving portion by a coefficient of about 0·02. The starting-pull was practically 100 per cent. more. It varied a good deal in the experiments, as the work was done with a hand-winch, and the dynamometer, inserted in the wire rope, had a limit of about 10 tons, so that it was rather difficult to get the exact starting-load.

The President.

The PRESIDENT asked what was the condition of the rollers and the roller-path.

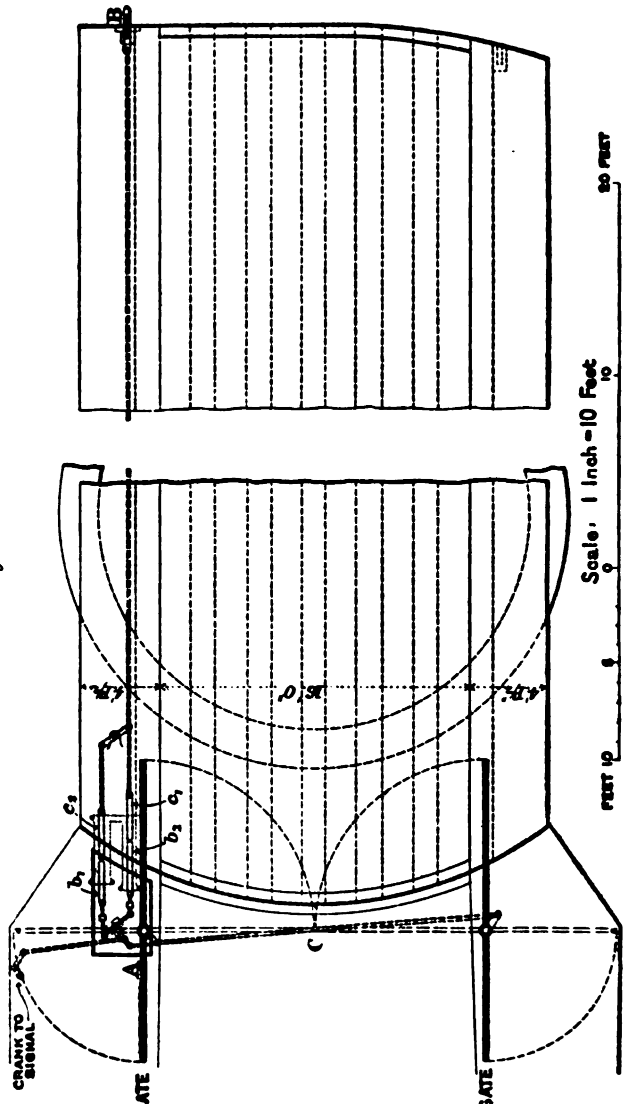
Mr. Copperthwaite.

Mr. COPPERTHWAITE said they were not treated at all: the dust was swept off the lower roller-path, and the rollers were quite dry. The other point to which he wished to draw attention was an arrangement, not very novel, but simple for the conditions under which it had

Mr Copperthwaite.

to work. A bridge built by the London County Council had to stand a large amount of criticism, and great care had to

Fig. 2.



Old Gravel Lane Bridge.

be taken for the safety of the public. *Fig.* 2 showed the general outline of the scheme, though it did not show how carefully the

Mr. Copperthwaite.

contractors had worked out the details. The operator's cabin was 30 feet away from the road, and the first condition was that he should not be able to move the bridge until the gates were shut. That was arranged by having a contact underground at C. The gates were made with centre pivots, so that the movement of one gate shut not merely half the road, but one foot-path as well, and on the other side of the road there was a similar gate connected with the first by cranks, as in level-crossing gates. When the gate was shut, a bolt was dropped on each leaf, and those two bolts made the contact at C. Until the gates were shut, the man in the cabin could not move the bridge at all. The interlocking was worked in the following manner There was a crank at A, connected with a short bolt b_1 and a longer bolt b_2. When the bridge was open, and the gate was in position, these bolts held the bridge. On the bridge itself there was a crank with a long bolt c_1 and a short bolt c_2; and the bolt c_1 went through into the other half of the bridge at B. When the gate was swung round the crank caused one pair of bolts to advance and the other pair to recede, so that when the gates were completely shut the adjacent ends of each pair of bolts were quite free. The operator in his cabin was thus able to open the bridge. When he closed it again, exactly the reverse happened. He swung the bridge into position while the gates were shut, and as the gates were opened for the public to go through, the lock was put in again. Precautions were taken against the gates being swung too soon by putting in a back lock, so arranged that the bolt could not be shot home until the other leaf of the bridge had come forward, and, by means of a little lever, had lifted the back lock which held that bolt. It was therefore impossible for anybody to get on the bridge while it was being opened.

Mr. Brereton.

Mr. C. A. Brereton, having had an opportunity of seeing the Bristol swing-bridge during its construction and after its completion, wished to bear testimony to the fact that it certainly had been one of the successful works of swing-bridge construction. It gave an impression of ample strength and stability, and of being well suited for the work it had to perform. No doubt, as Mr. Homfray had said, it was of the utmost importance that there should be no failure either in the bridge itself or in its working, because it was not only dealing with the railway- and road-traffic over it, but also the river-traffic under it, and that could not be kept waiting when once the signals had been given for the bridge to open. It was therefore of the utmost importance in all swing-bridges of that kind that there should be no possible hitch in opening or closing. The construction of the foundations

Mr. Brereton. in this instance had not been so difficult as in some other cases, and therefore the coffer-dam system adopted appeared to have answered in a very satisfactory manner. Of course in the Avon at low tide there was very little depth of water to contend with, and therefore the caulking of timber coffer-dams could be readily carried out. The advantage was that inside a coffer-dam the pier could be built exactly where it was wanted, whereas sometimes in sinking caissons or large monoliths through a great depth of mud or silt there was a tendency for them to drift out of the true position. With regard to the question of supporting the weight upon rollers, as Mr. Cruttwell had remarked, there was apt to be a difference between the weights that came upon the rollers when the bridge was actually working and when the bridge was in position and carrying traffic, and therefore some allowance had to be made to provide a margin for the rollers that were not actually in play when the bridge was turning. A centre pivot no doubt relieved the weight, and also it had an advantage where tail rollers could be used to guide the bridge and steady it in its turning; but in many cases where that was impossible, it was desirable to make the diameter of the roller-ring and also that of the rollers as large as possible. The question of interlocking was an important one, especially where a bridge had to carry both trains and road-traffic. In most of the swing-bridges he had been concerned with, it was done by shooting bolts, working alternately, putting one in and the other out—in fact, an arrangement somewhat similar to that explained by Mr. Copperthwaite. The adjustment of those bolts had to be done with a great deal of care. If the ends of the bolts were made somewhat in the shape of the ordinary bolt on a locking-bar of a switch, it added very much to the facility with which the bolts could be inserted and withdrawn. The Bristol bridge was a thoroughly practical example of what a swing-bridge of the kind ought to be.

Mr. Douglass. Mr. W. T. Douglass observed that Mr. Savile stated that in carrying out the foundations of the central pier of the Bristol bridge, a coffer-dam was erected, the piles being driven about 2 feet into the marl. He would like to know what arrangements had been made for filling the holes which the piles occupied, after the piles were removed. It appeared to him that it would never do to leave the bed of the river in that condition. Again, further on in the Paper Mr. Savile stated that the live load on the roadways was assumed to be 1·5 cwt. per square foot. Mr. Douglass imagined that would be excessive for a bridge of the kind, and he desired to know whether any experiments had been made before arriving at that figure.

Mr. J. S. Wilson, having seen the construction of the Pyrmont ridge at the bridge-yard, thought he might be able to add a few etails that would be of interest. The swing-span of the Pyrmont ridge and the caisson were constructed in Belgium by the Société nonyme des Ateliers de Construction de Hal, near Brussels, and e carried out the inspection of the work there on behalf of the ngineer to the New South Wales Government. The specification equired that the swing-span should be completely erected at the irder-yard and turned on its pivot before leaving. That of course ecessitated not only that special foundations should be prepared, ut that the work should be erected in a position where the ecessary space was available. It was also necessary that all he joints should be made in a suitable manner to support the reight of the bridge. When swung at the bridge-builder's works, ; must have weighed about 500 tons. The foundations under the oller-path were put in to a depth of about 1·28 metre. Reference ras made in the Paper to the difficulty experienced with regard to nachining, and the impossibility of turning the cast-iron ring and oller-paths. This part of the work was carried out as follows:— 'he cast-iron segments were planed parallel top and bottom in an rdinary planing-machine; the ends were then machined and the rhole of the segments bolted up into a ring. The ring was laid down nd carefully levelled with a surveyor's level, and the pivot to be sed for the bridge was mounted in the centre. A special carriage ras constructed with two rollers running on the top of the ring and onstrained to move round the centre pivot by a radius beam. A ool in a tool-box fixed on the carriage could be brought to bear on he vertical edges of the cast-iron ring, and the carriage was pulled ound by a horse (which had been trained to work a roundabout) arnessed to a projecting arm. The vertical edges were satisfactorily urned in that manner. The conical-faced treads had to be secured o the drum on which the whole weight of the bridge rested, ithout intervening packing of any sort, and the manufacturers nticipated that without very special care it would be difficult to nake a good job of the arrangement. While the cast-iron ring as perfectly level the drum with its flange angles loosely bolted n was put to rest on the top of it; the angles were then clamped own on to the ring, and while in that position the holes were mered through and the rivets were closed. With regard to the curacy with which this part of the work was fitted together, he ied all the rollers while they were supporting the whole weight to see w many were bearing. He found that he could only get a No. 6 eler (0·006 inch) between one roller and the upper tread, and Mr. Wilson.

Mr. Wilson. considered the adjustment was good. With regard to the temporary erection of the main girders, these were to have no initial camber, and they were packed up till the top booms were quite horizontal and the holes through the ties and struts were rimered through with pneumatic tools. The joints were made with turned bolts and parallel drifts, and the deflection was about 1 inch under the girder's own weight. He wished to ask Mr. Allan one question with reference to the camber of the bridge. To work the end-lifting mechanism, a shaft ran the whole length of the girders, and on account of the camber varying, the bearings of the shaft must get out of line. From the figures given in the Paper there appeared to be a good deal of friction, and he would like to know whether the Author recommended that system in similar cases, or whether he would consider it advisable to work the end-lifting mechanism by a separate motor at each end of the bridge. He thought the Author was to be congratulated not only on having designed a bridge so fine in appearance, but on having carried out the erection so successfully, and on the very satisfactory manner in which the bridge could be operated.

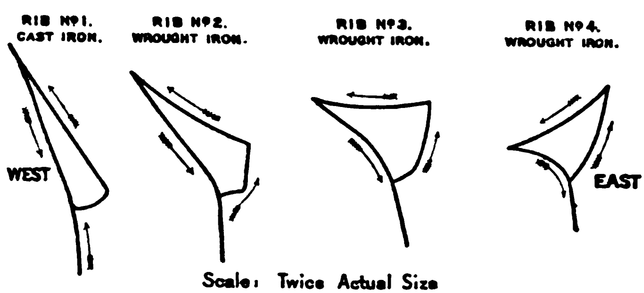
Mr. Homfray. Mr. S. G. HOMFRAY wished to answer one or two questions that had been asked. Mr. Copperthwaite had spoken of the roller-ring as being different from what it was in the Goole bridge. He had not closely inspected the plan of the roller-ring for the Goole bridge lately, and had not got it very clearly in his mind, but he thought the difference was rather more apparent than real. The axles were attached to a ring, and revolved with it around the centre pivot. In the case of the Bristol bridge and of many bridges that came before it—certainly in the Tyne bridge—a structure was built which used to be called a cobweb, and to that the roller-shafts were attached. It really shortened the roller-shafts and transferred the ring from the pivot to some distance out. The ring outside the rollers was not a very stiff one, and adjustment could be given easily and satisfactorily. He thought Mr. Copperthwaite had fallen into an error in regard to the weight per lineal inch. Mr. Homfray had a list giving particulars of some of the older and some of the newer bridges, and he found that in the Goole bridge the rollers were twenty-six in number, 3 feet in diameter, and 15 inches wide, and the swinging weight was 750 tons. That gave a load, per lineal inch of roller, of 1·93 ton. In the case of that bridge the roller-paths were made of cast iron with forged steel faces and the rollers of cast iron with steel hoops. Some little difficulty was experienced owing to the rolling out of the steel hoops, and they had to be rehooped. The bridge thus worked until as recently

as 2 years ago, when some of the rollers were replaced by cast-steel rollers without interfering with the traffic. In later bridges the load had been reduced considerably per lineal inch, and the steel faces had been given up. The Tyne bridge had cast-iron paths and cast-iron rollers, hooped with steel. In the case of the Bristol bridge there were cast-steel paths and cast-steel rollers, and therefore it was thought there was justification for putting rather more work on them than would have been the case with cast iron, especially when it was remembered that the bridge at Goole was still not exactly a nightmare to those who had to look after it. With regard to the tail-end bridges referred to by Mr. Cruttwell, there could be no question that where it was possible to get in a centre-press bridge with a tail-end roller-path, that was the best and cheapest. That that was recognized in Bristol was apparent from the fact that there were a considerable number of tail-end bridges there, the bridge under discussion being really the only live-roller bridge Bristol was an old port, and, as was often the case in the West of England, possessed many things that were being reintroduced at the present day. With regard to the tail-end bridges, he had spoken of 1,000 tons as being practically the limit, so far, of the load on a live-roller ring for a bridge, but, curiously enough, that was also the heaviest load that had ever been put upon a centre-press bridge. There were bridges of 950 tons in existence, one of them, the heaviest bridge made, being at the Royal Albert Docks. Beyond that weight, the centre-press became unwieldy, unless the hydraulic pressure was very high, and then it was necessary to provide for great strength to resist bursting. Hitherto, no bridge of more than 1,000 tons had been made of the tail-end pattern. With regard to the locking-bolts, it was necessary on a railway-bridge, if the locking-bolts were to be of real value, that the parts engaging in the socket should be parallel, so as to ensure the rails coming to the same point. If the bolts were tapered they would not so satisfactorily ensure the bridge coming into line, and he did not think a railway-engineer would be prepared to accept them. It was possible to have a locking-bolt with a tapered end for entering, as in the bridge which Mr. Cruttwell and he had had the pleasure of dealing with in years past, but that again would not do in the case of a swing-bridge where the locking-bolts acted to pull it up as it swung past. There would be a danger of the bolt flying in and something being carried away. If the fit of the bolt in the socket was made sufficiently fine, then, if the bridge was swinging too quickly, the bolt simply jumped past and did not engage. The question of camber brought him to the point that Mr. Homfray.

Mr. Homfray. while in the Pyrmont bridge only a comparatively small portion of the camber was taken out, in the Bristol bridge practically the whole of the camber was taken out by the hydraulic end gear, and sliding blocks were put in, leaving the bridge at practically the level at which it was built, and so reducing it to the condition of a fixed girder-bridge. As to the tail-end centre-press bridge, another great advantage over and above the simplicity and cheapness was, that when it was across the entrance it was resting upon six bearing-blocks of its own, and was in exactly the same position as a fixed girder without machinery. It rested on solid bearings which had no mechanical supports at all.

Mr. Elliott-Cooper. Mr. R. Elliott-Cooper observed that Mr. Savile had referred to the difficulty of being unable to shoot the bolts when the bridge was closed on account of a certain amount of twist caused by the effect of the sun, and Mr. Cruttwell had referred to an instance of the same effect in connection with the widening of London Bridge. A

Figs. 3.



good many years ago he built in Yorkshire a road-bridge consisting of two arches with spans of 166 feet each, and 60 feet wide. When one-half of the bridge was finished, he decided that, before taking away the staging, he would get a series of self-registered diagrams, showing what was the effect of the changes of temperature in 24 hours upon the structure, in order to ascertain the rise and fall of the centres of the arches, and also to see to what extent the rest of the structure would be affected by the rising and lateral movement of the outside ribs. It seemed to him that strains of considerable magnitude must occur in bridges and other structures of iron and steel from the effects of changes in temperature, particularly in a bridge, where the outer ribs or girders might be exposed to the sun's rays while the inner ones were in the shade. *Figs. 3* illustrated the curious movements of the bridge he referred to. The diagrams

were started late at night, and showed that early in the morning before sun-rise the four ribs rose fairly together. When the sun rose, the eastern rib took an upward and easterly direction, but as the other ribs were not exposed to the sun's rays they were pulled over horizontally. The westernmost rib, which was cast iron—all the others being wrought iron—was pulled over horizontally about ⅜ inch. When that rib reached a point when the sun left the east side and came across to the west, the eastern rib was beginning to get cool and was dropping, but it was pulled over in a westerly direction by reason of the rising of the westernmost rib. The other ribs were pulled over horizontally in the same way. Just as the two inner ribs had been pulled over horizontally to the eastward in the morning, so they were pulled over to the westward in the afternoon. That gave an idea, roughly, of the strains there seemed to be on a structure of this description. One part of the bridge having less natural movement of its own, through expansion and contraction of the metal, was dragged over by the cross bracings and floor-plates by reason of the greater movement of the outer ribs. There must be many cases where the strains were much severer; in such a climate as that of Africa, for instance, where the range of temperature in 24 hours at some parts of the year was often as much as 100°. Mr. Elliott-Cooper.

The PRESIDENT asked the nature of the "ribs." The President.

Mr. ELLIOTT-COOPER said the outer rib was a cast-iron arch with ornamental cast-iron spandrels, but the inner ribs were solid plate-girders with lattice spandrels. Mr. Elliott-Cooper.

Mr. J. G. CAREW-GIBSON remarked that having been at one time connected with the Public Works Department in New South Wales, he knew the original Pyrmont bridge, and was familiar more or less with the site of the present structure. It had been remarked already that European engineers would probably be most struck by the use of so much timber in the side spans in an important structure in one of the principal cities of the Empire; but that was due to the fact that while steel was not made in Australia—or at any rate was not made when he was there some years ago—there was some magnificent timber, and there was a strong feeling—with which he concurred—that where public money was being spent it was quite right that local materials, and as far as possible local labour, which had made the country, should have a preference. That was probably one of the main reasons why timber had been used in this case. But, apart from considerations of that nature, he was willing to believe, from what he knew of the circumstances, that timber was actually the more economical. Of course, there was the inconvenience of Mr. Carew-Gibson.

Mr. Carew-Gibson. constant repairs and renewals, but possibly the political consideration had led to that being subordinated. He had had to do with the construction and maintenance of a good many timber bridges while he was in New South Wales, in different parts of the colony, and his experience was that the useful life of those structures averaged, for the important parts of them, about 25 years. Most of the bridges in the colony outside the big towns had timber decks, and the decking being subject to the wear and tear of the traffic, its life would be about 12½ years, so that a bridge wore out two decks. At the expiration of that time, as a rule, it was not economical to go on repairing and renewing, but was truer economy to replace the structure with a new one. The bridges, as a rule, were built from the nearest suitable timber at the site of the bridge, no particular attention being paid to cutting timber at the proper time of year. He did not know whether it was such an important matter with Australian timbers as with timbers in other parts of the world, but he imagined it would have a considerable effect upon the life of the timber if it were always cut when least full of sap. He thought it very probable that if the timber for the bridges were selected a little more carefully, and felled at the proper season of the year, the life would average perhaps a few years more, but he doubted whether there would be much economy, as the cost would be considerable under the prevailing conditions. He regretted the Paper did not contain more details of the timber portion of the Pyrmont bridge, but judging from the information given, he thought Mr. Allan had improved on the designs formerly in use in New South Wales. He seemed to be using small scantlings, which was an important thing with Australian timber. The weak point in that timber was the heart, which was very often decaying before the tree had reached maturity. It was the first part of the timber to fail. It was quite a common thing to find beautiful sticks of timber absolutely hollow, sound at both ends but hollow farther along, so that Australian timber was very deceptive timber to deal with. By using small scantlings it was possible by avoiding the heart to get better timber, and he had no doubt the life of the timber in this bridge, therefore, would be more than the average. The deck upon the swing-span was said to be laid with tallow-wood blocks, and it would be interesting if the Author would say whether this was because tallow-wood was found to be the most suitable timber for wood-paving, or because it was a local timber, whereas jarrah, which seems to be about the only Australian timber used for the purpose in England, came from Western Australia. When wood paving was being laid in London, he had often looked at stacks of what were said to be jarrah blocks,

and wondered whether those responsible for their purchase could tell the difference between jarrah, karri, "red gum," "cabbage gum," and sundry other Australian timbers when in the form of blocks, many of them being extremely alike in appearance and yet very different in quality. The Paper did not go very much into details of the design, and hence criticism was not invited. But as a low first cost seemed to have been a primary consideration, it was perhaps a little surprising that a monolithic pivot-pier had been adopted. Whilst the design of this pier was quite sound, from an engineering point of view, and where the ground was at all doubtful was no doubt to be preferred, yet, in the present case, with an absolutely sound rock-bottom, a group of cylinders would have been equally effective, as there would be no danger of unequal settlement; and such a pier would probably have been cheaper, and would have taken a shorter time to construct. Perhaps the Author would say whether this question had been considered, and what had been the reasons influencing the design. No doubt the large pier, faced with handsome Pyrmont stone masonry, had a good appearance. He thought Mr. Allen was to be congratulated upon having designed and constructed a bridge which would bear comparison with similar structures in other parts of the world, and which, as a sound and practical piece of engineering, reflected credit not alone upon himself and the Public Works Department of New South Wales, but upon Australian engineering generally. Mr. Carew-Gibson.

Mr. Savile, in reply, explained that the hydraulic mains of the Bristol bridge were laid about 6 feet below the present bed of the stream. The idea was at some future period to dredge the river about 2 feet deeper there, so that there would always be a depth of 4 feet over the pipes. Further, in order to protect them, heavy iron cables had been laid across the river at a distance of about 50 yards up and down stream, so that any vessel dragging its anchor would probably catch it in the cables. There was also a rule of the river that no vessel was allowed to anchor within $\frac{1}{4}$ mile on either side of the bridge. He thought the mains ought to be fairly safe. With regard to bitumen sheeting under the wood paving, it was not nearly so good as asphalt, but it had been put down in order to reduce the weight of the swing-span as much as possible. It was a fairly easy thing to renew, but he was afraid it would not last as long as the wood paving; if it did, the bitumen sheeting could be renewed when the wood paving was renewed. With regard to the length of the axles, he thought one great advantage of keeping the axles short was that if an axle went wrong in any way it could be taken out, whereas if it was long the water-tight casing round the pier would prevent that from being Mr. Savile.

Mr. Savile. done. The chief reason why steel had been adopted for the material of the casing in place of cast iron was because steel was much cheaper, and as good strong timber fenders were provided, he thought that there would be no trouble. He could quite understand that, if a ship did run into the pier, cast iron might possess an advantage. With regard to Mr. Douglass's question about the pile-points below the concrete of the piers, no steps had been taken to fill up the holes, but the piles had not been universally driven below the excavation. Some piles stopped slightly above the bottom of the foundation and other piles which were fairly deep were cut off, so that he thought there was quite enough marl and piles against the concrete to obviate any risk of the piers sliding bodily, which apparently was the danger Mr. Douglass had in mind. With regard to the live load, it was quite possible $1\frac{1}{2}$ cwt. per square foot was excessive, but he thought that in designing the bridge there had been a desire to provide for future loads. It had been found that all bridges designed within the last 40 or 50 years had had their loads increased very much, and bridges soon became out of date; and as it was hoped that the Avon bridge would last longer than its builders, a large —perhaps impossible—increase in the loads had been provided for. Mr. Homfray having replied to the question about the time taken to swing the bridge, he would only add that the process of putting in or taking out the blocks occupied about 40 seconds, so that the actual time of swinging the bridge was about 1 minute. Mr. Thorpe had raised a question about the possible strain on the centre-pivot due to the turning-moment being unequal on the two arms. Mr. Savile did not think that was of much importance, because a greater strain was liable to come on the centre pivot due to wind, and that would be the case in a bridge with either equal or unequal arms. As the pivot had to be made strong enough to withstand that strain, he thought it was quite safe from any other slight strain that might occur. No saving in cost could have been effected if the bridge had been made with equal arms, because the swing-span would have been more expensive, and no appreciable economy could have been obtained on the south abutment, because the length of this was regulated by the length required to bend away the road to the eastward, and that could not be shortened much without making a very awkward corner.

Mr. Burge. Mr. C. O. Burge did not think there was anything he could very well say on Mr. Allan's behalf, except with regard to the question of the time. The 30 seconds he had mentioned as being the time occupied in swinging of the bridge was, as he had subsequently discovered, only the time taken in swinging, and 8 seconds were occupied in lifting,

so that really the comparison was between 38 seconds and 1 minute 45 seconds. In such cases engineers were governed by circumstances, quite apart from questions of time and cost, but still he thought it would be interesting to have further information on the subject of the relative advantages of hydraulic and electric working. Mr. Burge.

Mr. ALLAN, in reply, thanked the members for the consideration given to his Paper, and expressed his indebtedness to Mr. Burge for explaining the adoption of timber side spans in lieu of steel. In view of the heavy loads to be carried the span had been somewhat more difficult to design than it would have been had the more permanent material been decided upon. With regard to the wind-pressure on swing-spans with unequal arms, even with equal arms unbalanced wind-pressure had to be anticipated, and in the calculations for the sluing-machinery of the Pyrmont bridge a velocity of 30 miles per hour acting on one arm had been allowed for, the exposed surface being taken as the area of the hand-rail plus twice the area of the main girder as seen in elevation: this necessitated providing an estimated force of 15,475 lbs., applied at the pitch-circle of the rack, in the motive power. The Author agreed with Mr. Thorpe as to the importance of good workmanship in the manufacture and fixing of roller-paths, and, holding this opinion, he had spared no expense in stipulating for the best class of work. In the fixing of the path, however, no difficulty had been met with except the small matter of rubbing down a $\frac{5}{16}$-inch "pig in the track" due to working the masonry bed from one, instead of sixteen level points in the circle. Mr. Homfray had instanced a number of notable hydraulic swing-bridges in which the weight on the rollers was relieved by a centre press; but in a wide-decked high-speed swing-span with an easy-running turn-table, the friction to be overcome by the power applied at the pitch-circle of the rack was so small, compared with the constant accelerating force required to overcome inertia plus unbalanced wind-pressure (calculated at 7,752 lbs. as against 38,544 lbs. in the case of Pyrmont bridge) as to render a centre relieving-press unnecessary for economy in sluing, whilst the 18-inch diameter of the rollers and a weight of 1·2 ton per lineal inch on them, had not caused any appreciable wear after 30,800 openings in 5 years, and was within the bounds of good practice as indicated by the examples on p. 202. He could not follow Mr. Homfray's argument that six times as much gear had been provided at the Pyrmont bridge, the pinion on the armature-shaft meshing with the spur-wheel alone taking the place of the connecting-rod and crank at the Bristol bridge; from that point the train of gears was similar, the greater reduction at the Pyrmont Mr. Allan.

Mr. Allan.

Bridge.	Motive Power.	Rollers. Diameter.	Rollers. Face.	Pressure per Lineal Inch.
		Inches.	Inches.	Ton.
Harlem River four-track railway . . .	Steam	Outer 24 Inner 20½	Outer 10½ Inner 10½	1·65
,, ,, 3rd Avenue tram and road	,,	24	12	1·47
Rock Island railway and road	Electric	18	10	1·83
Thames River, U.S.A.	Steam	20	11½	1·96
Cardiff Bridge, England	Hand	18	9	1·21
Pyrmont Bridge, N.S.W., Australia . .	Electric	18	10	1·21

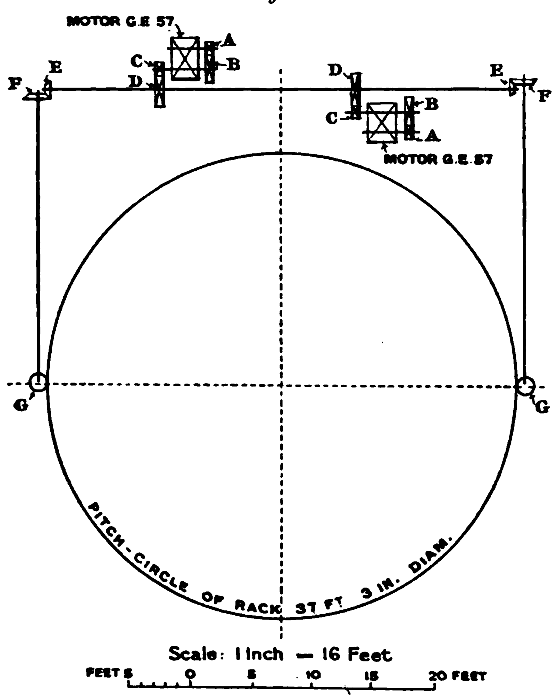
bridge being obtained by adopting a smaller pitch with consequent lighter gearing, finishing with a rack of $3\frac{2}{3}\frac{1}{2}$-inch pitch, as against 6 inches at the Bristol bridge. The general arrangement of the machinery at the Pyrmont bridge was the following (*Fig.* 4):—

First motion, armature-shaft, carrying pinion A with 19 teeth. Second motion, axle-shaft, carrying spur B with 66 teeth . .	3·473 to 1
,, ,, ,, ,, ,, pinion C with 14 teeth . Third motion, main driving shaft, carrying spur D with 74 teeth	5·29 ,, 1
,, ,, ,, ,, ,, ,, bevel pinion E with 15 teeth . . . . Fourth motion vertical shaft, carrying spur E with 39 teeth .	2·60 ,, 1
,, ,, ,, ,, ,, rack pinion G with 15 teeth Rack with 364 teeth	25·60 ,, 1

The foregoing gave 47·767 revolutions of the armature-shaft to 1 of the rack pinion, or 1,222·83 revolutions of the armature-shaft to 1 of the swing-span. With a large reduction, the effort to be exerted by the motive power was diminished, and the starting was made so smooth as to render the movement of a heavy swing-span difficult to detect. He concurred with Mr. Cruttwell as to the desirability of a stiff upper roller-path with equal distribution of weight in rim-bearing swing-spans, and considered these features to be essential in designing such structures. The whole weight of the superstructure of the Pyrmont swing-span was distributed at sixteen equidistant points on the circumference of the drum, as shown in *Fig.* 5 (p. 204). The facts of the conical tread being connected direct to the bottom flange of the drum, and of the drum being so deep, gave a particularly stiff path, the absence of which had caused the crushing of rollers and paths of some hand-power swing-bridges in New South Wales. In designing the section of the drum it had been treated as a straight girder, with a length equal to one-eighth

of its circumference, supported at the ends, and carrying a centre weight of 68 tons, the maximum stress in the flanges as adopted being 3·9 tons per square inch, and in the web 1·1 ton per square inch. By taking only 1¼ inch out of the deflections at the ends the dead load on the rollers was varied between 800 and 710 tons, and as this difference of 90 tons was transmitted through the distributing girders and stiff drum to the rollers, the difficulties in regard to altered adjustment of rollers referred to by Mr. Cruttwell had not Mr. Allan.

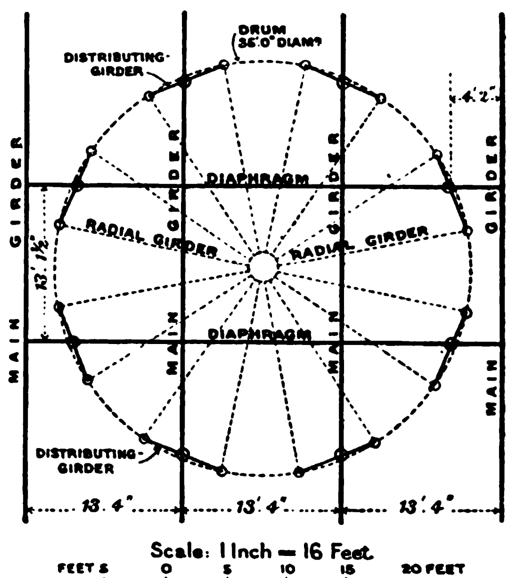
Fig. 4.



been met with. The object of placing a thin layer of sand on the bottom of the Sydney rest-pier had been to fill the voids along each pile, caused by the four flitches on the follower being driven below the clay bottom, and also to precipitate any possible remaining film of silt. It was considered that the richer concrete in the bottom batches would take up the sand and would set better than if it were deposited directly on the bottom, which, in view of the care taken in pumping out the silt, was an unnecessary refinement that had been omitted by the Author in constructing similar piers elsewhere. Regarding

Mr. Allan. the possible danger to cables from ships' anchors, it might be point out that there was no anchorage above or within reasonable dista below the bridge, the larger vessels being berthed at the differe wharves with the aid of tugs. The only contingency was the son what remote one of an anchor carrying away by accident whilst vessel was passing through the fairway, when a 4-foot cover wo be available over and above the probable maximum 26 feet depth future dredging. Mr. Wilson's description of the methods adopt in machining the track, and the steps taken during manufact to ensure the bottom angle-bars of the drum being truly ho

Fig. 5.



zontal for receipt of the upper conical tread, indicated the ca exercised by the manufacturers under Mr. Wilson's inspectio which had helped very much to facilitate erection; for wi track and pivot once bedded, everything had gone togeth without trouble, a result which, the Author considered, amp justified the expense incurred in stipulating for the swing-span bein erected and worked in the manufacturer's yard before shipmen Of the total deflection of 4¼ inches at the ends of the span only 1 inch was taken out by the end lifts, whilst the total spring in th longitudinal shaft was also 1¼ inch in a length of about 100 feet, th

Mr. Allan. haft being placed in such a position as to spring ¼ inch above and inch below a horizontal line, and ensure horizontality of the shaft at he moment when maximum effort had to be exerted by the motor, the ork to be done then quickly dropping either way. The worm-gearing, lthough having the known advantage of acting as a "stop" when ower was cut off, was responsible for the major portion of the friction lluded to by Mr. Wilson, and when designing the work, although he calculations by the usual formulas showed 8 HP. only as being equired, the Author decided upon a 35-HP. motor, his experience eing that with worm-gearing the usual calculations for friction ere quite fallacious. In the tests the maximum effort required rom the motor had been 29 HP. Except in longer-armed swing-pans, or where the ends were raised to full height, the Author referred the longitudinal centrally-driven shaft, as being the more irect and certain method of actuating the end-lifts, and of securing nore readily single control, the lifting of the ends to exactly the ame height, certainty of stopping the cams in the correct posi-ion with a simple strap brake, and mechanical connection between he lifting-gear and dial in the controlling-house. Mr. Carew-Gibson's experience of the average life of New South Wales timber tructures agreed closely with the Author's.[1] The felling of timber when the sap was "down" had been advocated in New South Wales or many years, but, owing to commercial considerations, without esult; to ensure as much seasoning as practicable, however, it was generally stipulated, in regard to the more important bridges of New South Wales, that the sawn truss-timbers had to be delivered at the ite before an advance on the contract would be made. The trusses n the side spans were 80 feet between the centres of triangulations, giving 82 feet 5 inches between the centres of the piers. The top and bottom chords each consisted of two sawn and planed flitches, 14 inches by 7 inches and 13 inches by 6 inches respectively, cut free of heart and sap-wood; each brace also consisted of two flitches bowed and stiffened with distance-pieces, the flitches varying from 13 inches by 6 inches in the end diagonals to 8 inches by 4 inches in the central bays, the vertical rods in pairs at each apex varying from $1\frac{7}{8}$ inch diameter at end intersections to $1\frac{1}{8}$ inch for cen-tral bays, and all rods being upset at the ends. The floor-beams were spaced 2 feet 8 inches apart, sawn 14 inches by 6 inches and 14 inches by 5 inches over apexes and intermediate points respectively, and were adzed down 2 inches at curbs to obtain part of the camber in the

[1] See P. R. Allan, "Timber Bridge Construction in New South Wales." Royal Society of N.S.W., 1895.

Mr. Allan. carriage-way. Tallow-wood, as the best timber for the purpose in New South Wales, was used for wood blocks, it being peculiar in its absence from gum-veins. It was delivered in flitches to facilitate inspection for class, and gauging to a width of 3 inches with a strict margin of $\frac{1}{16}$ inch or less, the object sought being to reduce spaces and secure a water-tight pavement. A group of cylinders would have been cheaper than the pier adopted, but difficulty had been anticipated in securing sufficient stiffness in the circular girder to give an absolutely unyielding path, which was perhaps the feature of the design. Apart from this, however, it had been deemed desirable that a solid pier should be adopted, in view of the heavy shipping which would use the fairways, and the unfortunate experience at Parramatta River bridge close by, where in collision a steamer lifted the braced group of cylinders bodily out of plumb.

Correspondence.

Mr. Brain. Mr. O. W. Brain, of Sydney, observed that the question of the motive power to be adopted for swinging the bridge appeared to have been a matter of utilization of local advantages rather than selection of the superior method for the work, both at Bristol and at Pyrmont. In the former case the Docks Committee's hydraulic power was at hand, while at Pyrmont the State had available its own electric supply, of such a character that reliability of service was ensured. No doubt serviceable operation of either bridge could have been obtained with either of the secondary powers under consideration. Mr. Allan's Paper showed that the results of working at Pyrmont over a period of 4 years had been entirely satisfactory, and doubtless it was safe to assume, from the absence of any statement in the Paper to the contrary, that Mr. Savile wished it to be understood that the equipment he described discharged in all respects the functions for which it was designed. At the same time, Mr. Brain would like to have seen a statement of the cost of power consumed in the operation of the Bristol bridge, which might have been compared with Mr. Allan's very complete figures. In connection with the latter, it might be mentioned that the charge of 1*d.* per kilowatt-hour made by the Railway Commissioners was for the power at the bus-bars of their power-house. The cost of the cables was a charge against the bridge, and the losses in the cables were included in the annual charge for power-

supply. Hence the low charge of 1*d.* per kilowatt-hour. Power Mr. Brain. might be obtained at the bridge at a flat rate of 1½*d.* from the City Council, who incurred all costs of transmission. In view of the cheap available electric power, the only commercially feasible methods of operation open to Mr. Allan had been direct electric working, and hydraulic working by means of electrically-driven pumps. There would not seem to be any excuse for the latter except habit, as a similar arrangement was even now occasionally installed for elevators, where the ordinary directly-operated electric elevators would be satisfactory and do the work at less cost. There might perhaps be an inclination to prefer a smaller gear-reduction than 1,223 revolutions of the armature to 1 of the swing-span. There would, in fact, have been no difficulty in dividing the former figure by six; but no object, except possibly an æsthetic one, would have been served. The motors would have had to be proportionately larger, heavier, and more costly. There might have been more difficulty in accommodating them on the swing-span, and repairs, if any, would have been more difficult and costly on account of the larger parts. This was pre-eminently a place which justified a small motor, so long as the loading was not carried to a point at which the reliability of the motor would be affected. The swing-motors, in fact, made a little over 3½ million revolutions per annum, or less than one-twentieth of what the same class of motors ordinarily did in traction service. The annual power-output also bore approximately the same relation. The damage resulting from the reversing of the motors, as a method of bringing the swing-span to rest, was only what might have been anticipated. This course was permitted in traction service only when everything else had failed; as, with a well-loaded car, high speed, and good adhesion on the rail, the reversing of the motors and application of current was very likely to be attended with serious damage. As a rule, the car-wheels slipped, but the bridge-gearing providing no such safety device, the probability of injury was much greater. This consideration did, however, suggest another method which was entitled to adoption for this class of work, particularly where the cost of current was of importance. He referred to the Raworth regenerative system, and he did so with confidence, as the results which had been obtained with the tramcar-equipment imported by the Railway Commissioners had been such that he would now have no hesitation in recommending Mr. Allan to install the system for bridge-work. The speed of sluing might be increased with a decreased consumption of power and without increased strain upon any part of the gear. In fact, the retardation was under better control and could be applied more

Mr. Brain. regularly than by any method of mechanical braking. It would hardly be necessary to explain that the principle involved merely the return to the line of the energy stored in the swing-span, which would otherwise be dissipated in heat at the brake-shoes. There would be nothing experimental in the adoption of the system in connection with the swinging of a bridge, as the whole of the requirements under such conditions had been met in tramway service. The latter work, in fact, was of a much more exacting nature and involved requirements considerably beyond those for the operation of a swing-bridge.

Mr. Buswell. Mr. Lincoln Buswell, of Sydney, remarked that in the 5 years which had elapsed since the Pyrmont bridge was opened for traffic, the working of the swing-span had disclosed one or two slight weaknesses. The pins supporting the top or movable foot-blocks of the end lifts had shown signs of bending, making the pins eccentric, with the consequence of the blocks sticking and thus being thrown at an angle, which, if allowed to remain, would have resulted at some time in serious accident. The difficulty had been overcome by easing the pins by $\frac{1}{32}$ inch, which allowed the weight of the ends of the span to be thrown on the outside of the boss in which the pins worked. No difficulty was now experienced. Again, on account of the high speed of the gate-motors, and their sudden stoppage when the attachment on the slotted bars came in contact with the circuit-breaker, a severe strain was thrown upon the levers and extended to the pinion-shaft on the motors, due to the momentum of the gate; and the pinion-shaft had on two or three occasions been broken, throwing the gate out of gear. This difficulty had been overcome by lengthening the levers connecting the solenoid brake and strap on the brake-wheel, and attaching thereto a dash-pot or air-cushion. Thus the motor was allowed to travel a few revolutions after the current was cut out, while the air was escaping from the dash-pot through a small valve, which when exhausted brought the strap hard on to the wheel at the same time as the gate was brought to rest. One dash-pot was fitted to each gate-motor, and had been found to work admirably. The coil given to the cables had been found to work fairly satisfactorily, but on account of the cables being fixed so tightly in the 7-inch opening at the top of the pivot, they had been found to be cutting, and thus in danger of a complete breakdown. An important alteration had therefore been made by inserting a series of flexible couplings; each cable was cut at the top of the pivot and distributed over a double-terminal granite slab, one on the permanent pivot and the other on the movable girders with suitable attachments; the two terminal boards were

coupled up by means of flexible couplings, and the cables were then carried to a junction-box and thence to the various controllers and the switchboard in the controlling-house. The division of the cables at various points afforded facilities for isolating a fault in a very short time. In connection with Glebe Island bridge, a work designed and constructed by the Author on similar lines to the Pyrmont bridge, and situated about 1½ mile away, a break actually occurred a short time ago, when a fault was definitely located in 7 minutes in a distance of about 5 miles. The cost of the flexible coupling was a little under £100. The whole arrangement now worked very satisfactorily. The coke-concrete foundation over the buckled plates for the wood blocks on this span had always appeared to him to be too thin, and he had been of opinion that the excessive pounding on the blocks by the heavy traffic over it, and the constant lifting and lowering of the span at the ends, would eventually crack it. Such had proved to be the case, the area on this portion of the bridge having been the most expensive for repairs. He thought that a better roadway would have been obtained by making the blocks 4 inches deep, the 2-inch space being made up by laying longitudinal planking on top of the concrete, and a groove being left for tramway-rails, the laying of which was now contemplated. The thickness as now laid had been adopted for lightness, it being impossible to increase the concrete. The wood-blocking on the side spans had answered admirably, though a little more camber in the roadway would have been an advantage. No expense for repairs had been occasioned since the blocks were laid, about 4 years ago. Mr. Buswell.

Mr. T. B. Cooper stated that the blows which occurred during the excavation for the centre pier of the Bristol bridge had been caused by the presence of large stones which lay in the gravel bed below the river-mud. These stones had interfered with the regularity and closeness of the piles of the dam. It had frequently been found that although a pile above the mud-level was apparently in true line the lower portion had been deflected several inches, leaving an opening between the piles which could not be got at for caulking. The water of the river had very free communication through the shingle at that level, and this underground channel, as it might be termed, had rendered the leaks difficult to attack, with the very considerable head of water which prevailed at high tides. The north pier had been more fortunate in this respect than the centre pier, as at the north side of the river the large stones were not so numerous as on the south. If he had similar works to do again, where such a large rise of tide had to be dealt with, he felt confident he would ask to be Mr. Cooper.

Mr. Cooper. allowed to adopt monoliths. It would be remembered that the works of the Bristol bridge were begun about 8 years ago, before it was generally recognized that the monolith system could be handled as easily and expeditiously as had since proved to be the case. By adopting that method, much of the excavation might have been grabbed out wet; and although pumping might have been needed occasionally if a large stone or other obstacle was encountered, the cost of this would not have been comparable with that of the dams used. This would be understood when he stated that the average pile of the dams was 52 feet long by 12 inches square. Again, once the monolith shoe had got into the red clay and the top was above high water of neap-tides, operations could have proceeded absolutely in the dry for several days, and the interior concrete hearting could have been put in with practically no attendant cost of pumping or washing down. It was interesting also to recall that, nearly at the bottom of the excavation for one of the two pits behind the tow-path pier (Fig. 2, Plate 4), human remains and a skull, this last practically unbroken, were discovered. It would be noticed that the strata here formed a hollow, and there seemed no doubt that the River Avon at one time took this course.

Mr. Dare. Mr. H. H. Dare contributed the following account of how the power required for turning the Pyrmont bridge had been calculated, and how the calculations agreed with the actual results. The total weight of the span when swinging was 797·6 tons, the radius of the rack-circle was 18 feet 7½ inches, and the radius of the drum was 17 feet 6 inches. It was assumed that the bridge would be opened or closed in 60 seconds, of which 24 seconds would be occupied in uniformly accelerating the speed, 12 seconds in turning the bridge at the maximum speed so produced, and 24 seconds in running with the current cut off, the speed diminishing evenly from the maximum to nothing. The calculations were based upon opening the span through 90°, but it was subsequently settled that 83° should be the maximum opening. The resistances to be overcome were:—

1. Rolling-friction.
2. Sliding-friction between the disks of the pivot under the radial girders.
3. Collar-friction of the rollers.
4. Inertia.
5. Unbalanced wind-pressure.

As the tests were made on a calm day, wind-pressure for purposes of comparison was omitted from the following calculations. It

formed, however, a considerable item when unevenly distributed over the span, and it was estimated that in the extreme case of an unbalanced wind-pressure of 30 miles per hour covering the whole of one arm only, the time required to open or close the bridge would be very nearly double that taken on a calm day, with the motors exerting the same power. Mr. Dare.

1. The rolling-friction, taking a coefficient of 0·003, was 5,036 lbs.

2. The sliding-friction between the disks of the pivot, taking a coefficient of 0·10, was 110 lbs.

3. The force at the rack to overcome the collar-friction of the rollers was estimated at 2,606 lbs. The design of the rollers was subsequently somewhat modified.

4. The inertia, which was by far the greatest resistance to be overcome, was determined by dividing the span into its component parts, and the resistance due to the inertia of the whole moving mass was found to be 23,069 lbs.

Therefore the power required at the rack-circle on a calm day, for sluing the bridge in 60 seconds, as originally calculated, was—

	Lbs.
1. Rolling-friction	5,036
2. Sliding-friction at pivot	110
3. Collar-friction of rollers	2,606
4. Inertia	23,069
Total	30,821

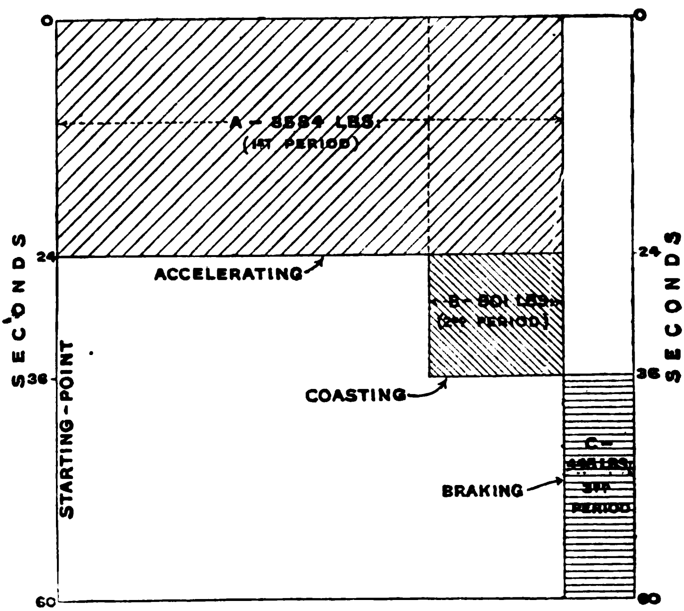
47·767 revolutions of the pinion on the armature-shaft = 1 revolution of the rack-pinion. The circumference of the pinion on the armature-shaft was 1·658 foot and that of the rack-pinion 4·570 feet. Allowing 100 per cent. for friction of shafting and gearing, the power required at the pitch-circle of the pinion on the armature-shaft was:—

$$\frac{30{,}821 \times 2 \times 4 \cdot 57}{47 \cdot 77 \times 1 \cdot 658} = 3{,}584 \text{ lbs.}$$

This represented the power required to accelerate speed and overcome friction during the first period of 24 seconds from rest (*Fig. 6*) on a calm day. The 5,384 lbs. given as the guaranteed starting-effort of the motors included also a provision for overcoming unbalanced wind-pressure. During the ensuing 12 seconds the resistance due to inertia disappeared, and the only power

Mr. Dare. required was that to overcome friction, namely, 901 lbs. During the final 24 seconds a retarding force must be applied, calculated upon the force required to overcome inertia, but deducting the retarding effect of friction in the moving parts. This was estimated at 445 lbs. The friction allowance for shafting and gearing was calculated to be 60 per cent. on the foregoing, but in order to ensure ample power this was increased to 100 per cent. when finally determining the capacity to be provided in the motors. The following calculations of the power actually developed had been made,

Fig. 6.



A = force required at pitch-line of pinion on armature-shaft to overcome total resistance and accelerate speed so that after 24 seconds the maximum motor-speed of 509 revolutions per minute, or 0·81 foot per second at the pitch-line of the rack-pinion, will be attained. This corresponds to 91 HP. with 100 per cent., or 72·8 HP. with 60 per cent., allowance for friction of gearing.

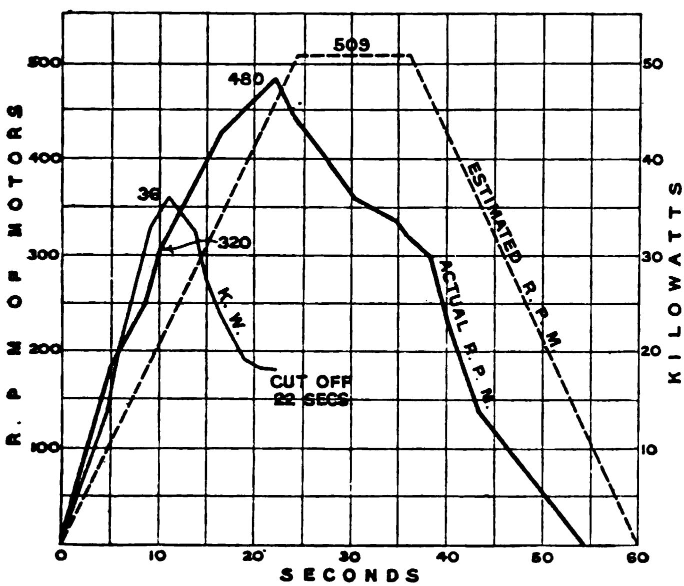
B = force required at pitch-line of pinion on armature-shaft to overcome rolling-, sliding-, and collar-friction, and maintain a speed of 509 revolutions per minute.

C = retarding-force required to bring span to rest.

based upon diagrams of trials of the swing-span supplied by the Author:— Mr. Dare.

Run No. 20.—This was referred to by the Author as the most economical run, and was illustrated in *Fig. 7*. Current was applied uniformly for 11 seconds, when the power required was 36 kilowatts, or 48 HP., and the revolutions of the motors 320 per minute. From the maximum of 36 kilowatts the power diminished to 18 kilowatts in 11 further seconds, during which the span gathered speed up to 480 revolutions per minute of the motors. At the end

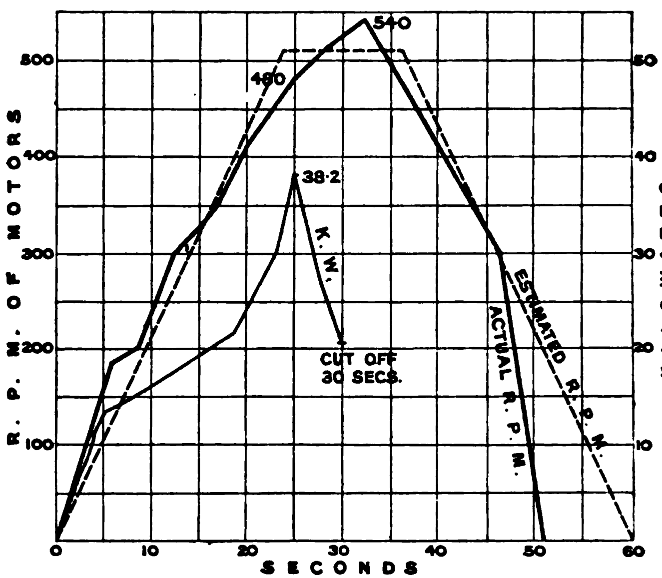
Fig. 7.



of 22 seconds power was cut off, and the span was brought to rest in 55 seconds. The main point to be considered was the uniform accelerating force required to overcome inertia, and the calculations in this and other cases were based upon the peak in the kilowatt-diagram, up to which the acceleration was fairly constant. The power required, neglecting the friction of the gearing, was 36·6 HP. The actual maximum power developed was 48 HP. The difference, 11·4 HP. or 31 per cent., on the assumption that 39,443 lbs. was, as calculated, the total force required at the rack, would represent the additional power required to overcome the friction of shafting and gearing.

Mr. Dare. *Run No. 10.*—In this run the acceleration-period was 25 seconds, and the total time for swinging 50 seconds. This case had been taken because the acceleration-period and the maximum number of revolutions of the motors were more nearly similar than in other runs to those in the original calculations, though the power-curve (*Fig. 8*) was not so even as in most of the other cases given in the following Table. Current was applied for 25 seconds, increasing in a fairly uniform manner to 38·2 kilowatts, or 51 HP., when the speed of the motors was 480 revolutions per minute. Reduced power was used for

Fig. 8.



5 seconds longer, the revolutions increasing to 540 per minute; and the current was then cut off, and the spans were brought to rest in 51 seconds. The results of this run, and also of other runs recorded in Table II, which gave diagrams from which the accelerating force could be calculated, were given in the following Table. It should be noted that in runs Nos. 12, 8, and 18 the maximum actual horse-power did not agree with that given in Table II, because the diagrams for these runs gave more than one peak in the kilowatt-curve, indicating a reduction in power

after reaching a certain stage, followed by a subsequent increase to the maximum horse-power. The first peak in the kilowatt curve, or the termination of the period of uniform acceleration, had been taken in these cases. Runs with similar acceleration-periods had been grouped together. Mr. Dare.

The average percentage of difference was 53 per cent. This agreed very fairly with the 60 per cent. estimated for the friction of shafting and gearing, which had been obtained by calculating in

PYRMONT BRIDGE. TABLE SHOWING HORSE-POWER AS ESTIMATED BY THE FOREGOING METHOD COMPARED WITH THE ACTUAL HORSE-POWER DEVELOPED IN SLUING THE BRIDGE.

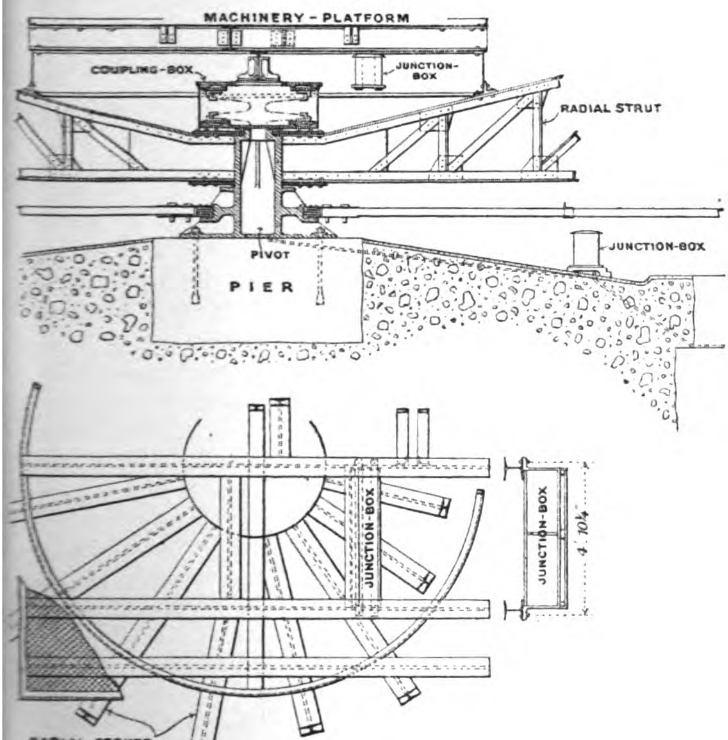
1	2	3	4	5	6	7
Period of Uniform Acceleration.	Number of Run.	Speed of Motors at End of Acceleration Period.	Power, calculated from diagrams, required in Sluing, *ex* Friction of Shafting and Gearing.	Actual power developed by the Motors.	Difference between cols. 5 and 4.	Percentage of Difference, representing Friction of Shafting and Gearing.
Seconds.		Revs. p. Min.	HP.	HP.	HP.	Per Cent.
5	12	250	45·4	67	21·6	48
7	11	300	47·6	67	19·4	41
7	8	250	34·0	55	21·0	62
7	9	275	40·6	74	33·4	82
9	4	290	40·1	57	16·9	42
9	7	275	32·9	58	25·1	76
9	5	335	46·3	72	25·7	55
10	18	320	39·5	70	30·5	77
11	20	320	36·6	48	11·4	31
17	14	360	31·8	45	13·2	41
25	10	480	39·4	51	11·6	29

detail the friction of each set of gear. The tabulated results appeared to indicate that, though the actual periods of acceleration and cut-off did not coincide with those allowed in the original calculations, the method employed in estimating the power required was reasonably correct. The deflections of the ends of the span, with the bridge swinging, had been calculated to be 3·89 inches for the outer and 4·03 inches for the inner main girders. The actual deflection was $4\frac{1}{4}$ inches.

Mr. Hanna. Mr. W. J. HANNA observed that when he took over the Pyrmont bridge immediately before Mr. C. W. Darley left for England, the caisson was, in consequence of the "blow," being sunk in the wet, and at that time it was thought possible to bed the cutting edge for more than half its periphery on the solid rock, at about 3 feet 9 inches above contract depth, and for the remaining distance to make good the space between the rock and the cutting edge with bags of concrete placed by divers after undercutting the clay. On reaching this less depth, however, it was found that the caisson was bearing on such a small portion of the ring that it was deemed desirable, in order to avoid risk, to carry the caisson to its original contract depth. It was doubtful whether the water could have been pumped out, and such a satisfactory foundation obtained, without adopting this course. The blow referred to in the Paper was probably due to the stiff clay not following the quick cant of 11 inches which occurred when pumping out the water, thus leaving a space along the outer wall of the caisson down which water found its way, ultimately bursting under the cutting edge. Had the caisson been pumped out a few feet before the cutting edge touched the high side of the rock, the canting might possibly have been diminished; but, with an unyielding stratum on one side, unequal settlement was to be anticipated, which the Author endeavoured to meet by leaving a large bed of clay on the low side. With the large diameter of the coil of cables at the top of the pivot, the opening and closing of the Pyrmont swing-span occasioned such a small amount of movement as to cause no trouble; but at the sister bridge at Glebe Island, where only a limited amount of cable was available and a much smaller diameter of coil had consequently to be adopted, failure had ensued in two of the leads in cables after about 12,000 openings, necessitating the introduction of a flexible connection between the standing and the moving parts of the cable at the top of the pivot, which it had been thought desirable to adopt also at Pyrmont. This device had proved eminently satisfactory in the past, and no trouble was anticipated in the future. In the hope, therefore, that it might be of some assistance to those interested in the design and construction of swing-bridges, the following description of the mechanism was given, illustrated by *Figs. 9* and *10*. The whole of the electrical apparatus in connection with the bridge was controlled from the cabin on the swing-span. This necessitated the provision of forty-eight conductors connecting the stationary equipment with the controlling-gear on the bridge. In order to gain flexibility, the two mains were furnished with two conductors, each

in the coupling-box at the pivot, bringing the total number of connectors in the box to fifty. The connectors included, besides the mains from the power-house referred to above, the leads for the gate-motors and lighting, and the telephone-service. The coupling arrangement consisted of two horizontally-placed circular rings Mr. Hanna.

Figs. 9.



PLAN OF MACHINERY - PLATFORM

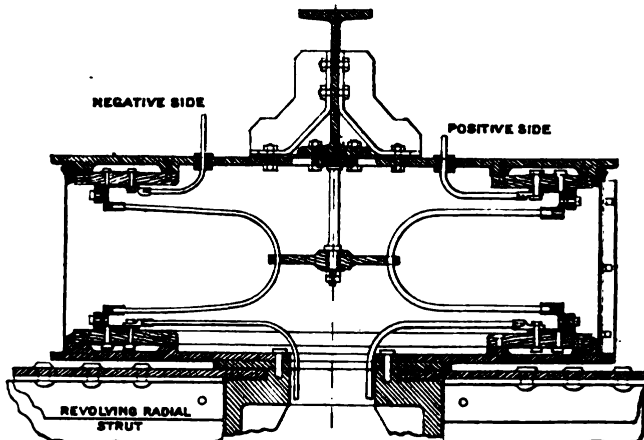
Scale 1 Inch – 6 Feet.

FEET 5 4 3 2 1 0 5 10 FEET

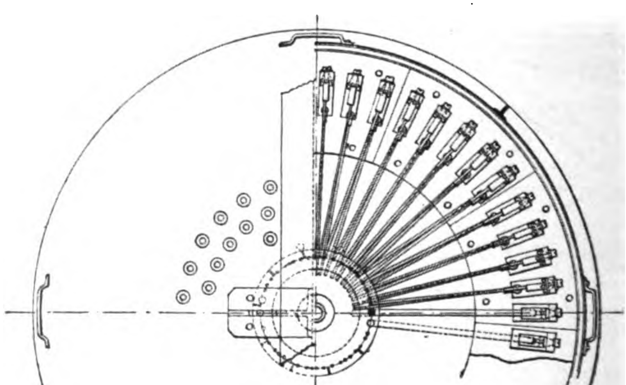
of terminals, each 3 feet 6¾ inches in diameter. Both were concentric with the pivot, one being secured to the bridge at a height of 12 inches above the other, which was mounted on the pivot. Each ring consisted of fifty terminals, which were fixed on a number of easily replaceable marble slabs. Each terminal of the upper ring was connected by flexible cable to the terminal of the lower ring which

Mr. Hanna. was immediately below it when the bridge was closed. The length of each flexible cable was 30 inches, which permitted the bridge to

Figs. 10.



DETAIL OF COUPLING-BOX



PART PLAN OF TOP OF CAST-IRON FRAME.

PART PLAN SHOWING ARRANGEMENT OF CONDUCTORS

Scale: ¾ Inch = 1 Foot.

INCHES 12 8 4 0 1 2 FEET.

turn through an angle of more than 90° in either direction from the closed position. To the ends of each flexible connection were sweated shaped connectors, which were held by set-screws in recessed

terminals on the cabin and pivoted conductors on the marble slabs. Mr. Hanna.
In each ring there were ten slabs of marble on which were mounted five terminals, facing outwards for accessibility. This arrangement allowed of a terminal or a slab of five terminals being quickly replaced in case of a short-circuit or broken connection. The positive and negative main connections each consisted of two cables in parallel, made of one hundred and five wires, No. 26 S.W.G., with vulcanized rubber insulation and braided covering; and each of the remaining connections consisted of twenty-five wires of No. 26 gauge similarly protected. The flexible connections looked inwards from the terminals and were held by a wooden guide which kept them uniform and allowed them to move only in a predetermined path. The special features of the design were ease and quickness of repairs and accessibility of the whole of the parts for cleaning or inspection without taking to pieces. The conductors on the swing-span and the pivot passed through junction-boxes to facilitate testing and changing over in case of trouble. The coupling-box was made dust- and water-proof by a detachable cylindrical sheet-iron cover which could be quickly moved when inspection was necessary. Seeing that this high-speed swing-span had now been opened and closed 30,800 times, involving 246,400 individual gate-movements without accident or any expenditure on repairs, where the traffic was particularly heavy, consisting approximately of 6,000 vehicles and 12,500 pedestrians per diem, it left little to be desired in the matter of design.

Professor W. C. KERNOT observed that the questions about the Prof. Kernot.
Pyrmont bridge which suggested themselves to him were the following:—(1) The comparative merits of the solid centre pier as compared with one consisting of six or eight cylinders, as used at several other swing-bridges in Victoria and South Australia. The latter construction would certainly have saved some costly work in levelling the rock, for the separate cylinders need not have been taken down to the same level; it would also have reduced greatly the volume of concrete needed. Further, cast-iron cylinders as used in the Victorian and South Australian bridges would have been much more durable, especially in the salt water, possibly made more corrosive by impurities from the shipping and the surface drainage of a densely-populated manufacturing district. (2) The comparative merits of girders above or below the deck. In the Australian bridges referred to above, the girders were above the deck, and acted either as the ultimate handrail or as a barrier between the carriageway and footway. They allowed of the maximum headway underneath, thereby

Prof. Kernot. obviating the necessity of opening the bridge for small vessels. On the other hand, the arrangement at Pyrmont required much lighter cross girders and distributed the weight better on the rollers. (3) Would it not have simplified construction somewhat to have had the bottom members straight instead of curved? In view of the importance of the bridge and its proximity to the centre of a large city, the timber approach-spans seemed hardly appropriate, intervening as they did between an elaborate and magnificently equipped swing-span, and an approach-viaduct of great architectural pretensions, the parapet alone of which abounded in massive and costly enrichments. No doubt ironbark was a fine and durable timber; but surely the extra expense of steel would have been justified, even if the architectural adornments had been somewhat reduced in cost to help meet it. The approach-gradients, not given in the Paper, were undesirably steep, and that on the eastern or city side presented an ugly and unnecessary break that was an impediment to heavy traffic.

With reference to Mr. Savile's belief that the Bristol bridge was "the only double-decked swing-bridge of anything like its size in existence," a double-decked railway and road swing-bridge of much larger dimensions was erected nearly 30 years ago at Albany, America. That swing-span was 397 feet long. The foundation of the towpath pier seemed questionable. Surely it would have been better to carry it down symmetrically to the gravel. A composite foundation as shown suggested possibilities of unequal settlement and loss of verticality. The arch in the centre pier was unusual, and its purpose not obvious. In cross section DD (Figs. 2, Plate 4) there appeared to be an excessive thickness and weight of concrete under the oak blocks and asphalt.

Mr. Robertson. Mr. F. E. Robertson suggested that the girders of the Pyrmont bridge were much too shallow, and the panels too short for an economical and rigid design: the reason for this was not clear, as there seemed to be plenty of room between high-water mark and the roller-path. Two girders of a reasonable depth would probably have been better than the four shallow ones actually used. The Paper did not say where the girders were built, and it might be remarked that the troubles with the turning-gear were entirely due to poor work. There was no difficulty in making rollers strictly interchangeable.

There were several points in the design of the girders of the Bristol bridge which seemed open to criticism. It was presumed that the reduction of ½ ton in the unit-stresses of the swing-span was an implicit recognition of the heavy reversals of stress which occurred

in it; but it would be preferable to allow definitely for these reversals by figuring them on the stress-diagram and adding, say, half the area required for the minor stress to that required for the major. By the method adopted, members having no reversals got an allowance which they did not want, while others which had heavy reversals received an insufficient allowance. The statement that a string of heavy goods-locomotives was equal to 1·66 ton per lineal foot was rather misleading, as the equivalent uniform load depended upon the length loaded. For the stringers it would be just about double. If the web-members, then, had been proportioned on the data given, they would all be much too weak. The object of the "point of contraflexure" in *Fig. 4* was not clear. There were an infinite number of such points in a beam with a rolling load, and certainly no such point could occur as shown in the diagram, in the midst of a panel of a truss. The section of the chord shown in Fig. 5, Plate 4, though quite common, was essentially bad. From the figures given, the area of the sides appeared to be 40 square inches, and of the bottom plates 105 square inches: it would be very much better if these proportions were reversed, the bulk of the metal being put into the sides, and thus receiving stress directly from the braces and gussets. As it was, five-sevenths of the total stress had to be transmitted through the edges of the trough-plates to the bundle of bottom plates, which it reached by the inefficient means of $\frac{7}{8}$-inch rivets $4\frac{1}{8}$ inches long. He suggested that as hydraulic power was used, rams hauling direct on a pitch-chain would have been a simpler gear than that adopted. Mr. Robertson.

Mr. Walter A. Smith mentioned that the maintenance of the Pyrmont bridge had come under his charge as Metropolitan Engineer after its completion in 1902, and from that time forward the whole structure had been an unqualified success, as regarded both road- and harbour-traffic. The former comprised nearly 6,000 vehicles per day, while during the year the average number of vessels passing through the opening span per day was thirty-two. In the 4 years during which this structure had been under his control, the openings of the swing-span numbered very nearly 25,000, and in not one opening had serious delay been caused to vehicular traffic, nor had any hitch or breakdown occurred with any part of the machinery. The coke concrete used on the swing-span was not strong enough to withstand the enormous traffic together with the repeated flexure of the girders and roadway of this span whilst opening and closing. This concrete had had to be partly replaced by stronger material, and a covering of "malthoid" had been placed over the concrete and under the wood blocks to prevent leakage of water from the roadway to the machinery below. Mr. Smith.

Prof. Warren. Professor W. H. WARREN observed that the distinctive features of the Pyrmont bridge were the arrangements for sluing the swing-span, for lifting its ends, and for working the roadway-gates on the side spans by means of electric motors supplied from the tramway power-house. He considered these arrangements to be entirely successful; the opening and closing of the bridge was effected in a rapid and at the same time economical and satisfactory manner. The details of the design of the main trusses and of the floor-system of the swing-span, and the method employed for distributing the load upon the rim-bearing turn-table, by means of short distributing girders, had all been carefully worked out, and appeared to him to be satisfactory. In regard to the design of the Howe trusses in the side spans, wherein ironbark timber was used throughout—except for the vertical tension members, which were of steel—a large number of bridges had been constructed in this manner in New South Wales. Where a strong, durable, and thoroughly satisfactory timber such as ironbark was available at a moderate cost, the method adopted was entirely successful; but in other countries, and generally, it would be found in his opinion to be more economical in the long run to substitute steel Pratt trusses for the Howe timber trusses. The chief difficulty in the design of the Howe truss occurred at the joints in the bottom-chord, the efficiency of which, no matter how well they were proportioned, was dependent upon the shearing-strength of the timber. In ironbark timber the shearing-resistance along the fibre was about 2,000 lbs. per square inch, and bolts did not work loose in it.

In the swing-bridge over the River Avon, there appeared to have been no attempt to distribute the load uniformly over the rollers. Again, the main trusses appeared to him to be inferior in design to those of many modern swing-bridges built in America—such as the bridge over the Harlem Canal by Professor Burr, the Harlem River bridges by Mr. Katte, and also bridges by Mr. Theodore Cooper and others—in regard to economical strength and stiffness.

Mr. Allan. Mr. ALLAN, in reply, observed that Mr. Brain's advice had been so amply borne out in the practical results obtained at the Pyrmont bridge, that, if he were designing another electric swing-span, he would seriously consider the introduction of the Raworth regenerative system in lieu of a mechanical brake. The suggested improvement, however, would affect only the cost of sluing the swing-span, which if eliminated would mean but a saving of £12 per annum, less the interest on the difference in cost between the improved apparatus and a mechanical brake; so that, from a com-

mercial point of view, there was not—with the cheap power available—much margin for obtaining a more economical result. As to the difficulty with the coke-concrete referred to by Mr. Buswell, he had purposely limited the thickness of this concrete foundation, the cost of occasional renewal with cheap local material being less than the interest on the cost of steelwork to carry any additional dead load; moreover, with more attention to the surface dressing of the wood paving, water was now prevented from finding its way to the coke-concrete, and the life of the latter was consequently lengthened. Had data similar to those now given by Mr. Dare been available, they would have saved Mr. Allan a considerable amount of anxious thought as to the sluing-power to be provided. The figures showed how closely the 60 per cent. total friction-losses calculated for each set of gears agreed with the results obtained in actual working. Mr. Allan considered it desirable, however, in swing-spans of a similar character, to allow 100 per cent. for friction-losses in gearing and overhauling of the shafting between motors and rack, as adopted in the Pyrmont design, the additional cost being small and in the nature of an insurance against possible errors in manufacture and erection. Whilst it was possible that, as suggested by Mr. Hanna, had the water been pumped out of the caisson before reaching the rock, the "blow" might not have occurred, yet the contract had so bristled with the possibilities of heavy claims for extras as to make it desirable to adhere to the specification, a decision which, in spite of the blow, financial results had justified. The introduction of a flexible cable-connection between the fixed and the moving parts of the swing-span, described in detail by Mr. Hanna, had removed a weak spot in the design. In adopting a deck bridge, Mr. Allan had been influenced by the fact that in such a design the whole width of roadway right up to the curbs was made use of, whereas, when girders rose above the deck—as mentioned by Professor Kernot—the traffic pulled away from the girders, leaving a practically unused deck-space of 2 or 3 feet long at each curb-line. Again, the width of the boom had to be added to the length of the girders in order to obtain the same effective waterway. Whilst it would have simplified construction if the bottom members had been made straight, yet it was considered that the improvement in appearance had justified the small additional cost. He had been limited to the adoption of timber side-spans, but had considered it desirable to provide stone parapets on the approaches in keeping with the iron hand-railing extending from abutment to abutment, the whole presenting—from the deck—the same appearance as if a steel substructure had been

Mr. Allan.

Mr. Allan. adopted. He regretted the break of gradient in the approach, which was due to a departure from the original design in order to minimize land-resumption, and a subsequent effort to recover lost opportunities. If two girders had been adopted as suggested by Mr. Robertson, it would have meant an entirely different design with accompanying heavy cross girders, and a difficulty, as pointed out by Professor Kernot, in obtaining a satisfactory distribution of the weight on the rollers. The 15 feept deth—where four girders were provided—was economically proportioned, as shown by the weight of material in the web as compared with the booms; whilst the short panels adopted were an important factor in increasing the stiffness, the rigidity of the span when swinging at high speeds being perhaps one of the most noticeable results obtained. In view of the heavy road- and shipping-traffic, it reflected credit on Mr. Smith's administration that the span had been for such a long period operated without hitch or complaint from the divergent interests involved. He was pleased that the electric equipment and the method of distribution of the load of the swing-span, as well as the general design of the trusses for the side-spans, were in accord with the views of Professor Warren, who had designed some of the larger bridges in New South Wales, and was well acquainted with the durability and other characteristics of Australian hardwoods.

Mr. Savile. Mr. Savile, in reply to Mr. Brain's question as to the cost of the hydraulic power for swinging the bridge, stated that the quantity of water used for the complete process of opening and closing was 182 gallons, and, basing the cost on the assumption that the pressure-water cost 2*s*. per thousand gallons (the price charged by the Docks Committee to outside consumers), the cost of each swinging amounted to 4·37*d*. The bridge had been working now for more than 10 months since the date of opening, and had been swung on an average about 270 times per month, the working of the machinery being entirely satisfactory. Referring to Professor Kernot's remarks, the reason for the towpath pier being founded partly on piles and partly on the gravel was that the design of the north approach was altered after this pier had been built, and as the alteration considerably increased the load which the pier had to carry, the concrete columns were added, and all the weight of the girders was carried on them. The arch in the centre pier had the advantage of reducing the obstruction to the flow of the river somewhat, and it also saved a considerable amount of concrete, while still leaving the pier quite strong enough to carry its load. Mr. Robertson was correct in assuming that the reduced working-stresses in the main girders of the swing-span had been adopted on

account of the reversals of stress which occurred under different conditions of loading. With regard to his criticism of the statement in Mr. Savile's Paper that a string of heavy goods-locomotives was equal to 1·66 ton per lineal foot, he appeared to have overlooked the fact that the Author went on to say, "with a load of 18 tons on an axle." This load per lineal foot was quite correct for any span exceeding 40 feet and had been adopted for the main girders; but in designing the cross girders and rail-bearers the heaviest axle-load had of course been allowed for. As to the point of contraflexure in *Fig. 4*, Mr. Savile was quite aware that this point was movable under the various conditions of loading, but the diagram professed to show only the stresses for one particular distribution of the load, and it gave the theoretical position of the point under this condition. As, however, very heavy flange-stresses occurred in this neighbourhood when the bridge was swinging, the booms were designed to take these stresses, and so had a very large margin of safety for the stresses which might occur under the live load. With reference to Professor Warren's remarks as to the distribution of the load over the rollers, it appeared to Mr. Savile that the annular girder, with the help of the stiff cross girders over it, was sufficient for distributing the load. At any rate, as far as could be seen, all the rollers did their work, as no idle rollers had been detected since the bridge was opened. Mr. Savile.

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23 April, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

It was resolved—That Messrs. E. R. Dolby, F. Hudleston, E. W. Monkhouse, R. J. G. Read, A. W. Szlumper, T. Frame Thomson, and J. J. Webster be appointed to act as Scrutineers of the Ballot, in accordance with the By-laws, for the election of the Council for the year 1907–1908.

The Council reported that they had recently transferred to the class of

Members.

William Corin.
William Liston Douglass.
John May.
Stephen Westropp Stacpoole.

And had admitted as

Students.

Hermann Charles Bender.
John Hyslop Gardner, B.Sc. (*Glas.*)
Cyril Thomas, B.Sc. (*Durham.*)
Sydney Upton.
James Douglas Whittall, B.Sc. (*Manchester.*)

The Scrutineers reported that the following Candidates had been duly elected as

Members.

Robert Henry Haynes.

Harry Arthur Ruck-Keene.

Associate Members.

Thomas Patrick William Barty, B.Sc. (*Edin.*)

Archibald Carmichael, Stud. Inst. C.E.

Morton Farrer Cochrane, Stud. Inst. C.E.

Alexander Walker Duncanson, B.Sc. (*Victoria*), B. Eng. (*Liverpool*), Stud. Inst. C.E.

Spencer Pelham Flowerdew, Stud. Inst. C.E.

Richard Samuel Gardiner Fowler, B.A., B.A.I. (*Dubl.*), Stud. Inst. C.E.

Vivian Gordon, Stud. Inst. C.E.

Philip Rufford Hewlett, Stud. Inst. C.E.

Robert Charles Inglis, Jun., B.Sc. (*Edin.*)

Richard Edward Michael, Stud. Inst. C.E.

William Arthur Moyers, B.A., B.A.I. (*Dubl.*)

James Barclay Peat.

Bertram Darell Richards, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.

Howard Lecky Sikes, B.A., B.E. (*Royal*), Stud. Inst. C.E.

John Harold Clayfield Taylor, Stud. Inst. C.E.

George Walter Tripp, Stud. Inst. C.E.

Associates.

Mephan Ferguson.

John Roskill, K.C., M.A. (*Oxon.*), B.Sc. (*Manchester.*)

ANNUAL GENERAL MEETING.

30 April, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

The Notice convening the Meeting was taken as read, as well as the Minutes of the Annual General Meeting of the 24th April, 1906, which the President was authorized to sign.

The Report of the Council upon the Proceedings of The Institution during the Session 1906–1907 was read, the Statement of Accounts being taken as read.

After consideration, it was resolved,—That the Report of the Council be received and approved, and that it be printed in the Minutes of Proceedings.

The Scrutineers reported the election of the Council for 1907–1908 as follows[1]:—

President.

Sir WILLIAM MATTHEWS, K.C.M.G.

Vice-Presidents.

William Robert Galbraith.
Sir Edward Leader Williams.
James Charles Inglis.
George Henry Hill.

Other Members of Council.

John Audley Frederick Aspinall.
John Benton, C.I.E.
Benjamin Hall Blyth, M.A.
Cuthbert Arthur Brereton.
Robert Elliott-Cooper.
Rookes Evelyn Bell Crompton, C.B.
Joseph Davis.
George Frederick Deacon, LL.D.
Francis Elgar, LL.D., F.R.S.
Maurice Fitzmaurice, C.M.G., M.A., M.A.I.
Robert Abbott Hadfield.
Charles Augustus Harrison, D.Sc.
Joseph Hobson.
Walter Hunter.
George Robert Jebb.
John Henry Johns.
Sir William Thomas Lewis, *Bart.*
Sir George Thomas Livesey.
Anthony George Lyster.
Alexander Ross.
John Henry Ryan, M.A.
Alexander Siemens.
John Strain.
William Cawthorne Unwin, B.Sc., LL.D., F.R.S.
William Barton Worthington, B.Sc.
Alfred Fernandez Yarrow.

[1] The Council commence their year of office on the first Tuesday in November, 1907.

Resolved,—That the thanks of the Meeting be given to the Scrutineers, and that the Ballot-Papers be destroyed.

Mr. J. J. Webster responded on behalf of the Scrutineers.

Resolved,—That the thanks of The Institution be given to Messrs. P. D. Griffiths and J. M. Dobson, for their care in auditing the Accounts for the past financial year; especially to Mr. J. M. Dobson for his gratuitous service in the matter; and that those gentlemen be re-appointed Auditors for the current financial year.

Mr. Chevalier acknowledged the Resolution on behalf of the Auditors.

Resolved,—That the thanks of the Meeting be given to Mr. James Forrest, Honorary Secretary, to Dr. Tudsbery, Secretary, and to the members of the Staff, for the manner in which they have conducted the business of The Institution during the past year.

Dr. Tudsbery acknowledged the Resolution.

Resolved,—That the thanks of this Meeting be accorded to Sir Alexander B. W. Kennedy, President, for his conduct of the business as Chairman of the Meeting.

The President acknowledged the Resolution.

The proceedings then ended.

REPORT OF THE COUNCIL, 1906–1907.

The Council have pleasure in reporting, in accordance with the By-laws, on the state of The Institution as follows:—

The year under review has witnessed a considerable addition to the Roll—a satisfactory feature from two points of view: First, that one-half of the total increase has taken place in the Student Class; and, secondly, that a very large number of those elected have been drawn from that class, and have given evidence of close adherence to the general conditions of training advocated by the Council.

The number of candidates for admission into The Institution has been again very large, and the inspection of their qualifications under the exacting conditions of the present rules has involved considerable labour.

The operations directed by the Examinations Committee of the Council have been correspondingly extensive. Altogether 220 Candidates were examined for Studentship, and 422 presented themselves for the Institution Associate Membership Examinations. Two-thirds of those elected Associate Members during the year were qualified by the Institution Examination—the remaining third by other exempting qualifications. The regulation and maintenance of the standard of these examinations forms no light task, especially in association with the scrutiny of those degrees and diplomas which are recognized as exempting therefrom. To the list of these have been added during the year, under certain conditions:—

With respect to Studentship:—

University of New Zealand:—The Combined Preliminary and Entrance Examinations in Engineering.

South African College, Cape Town:—The Preliminary Examination in Engineering.

University of Sydney:—The Entrance Examination for the Department of Engineering.

With respect to Associate Membership:—

University of New Zealand:—B.E. degree (in the Department of "Civil," or "Mechanical" or "Electrical" Engineering).

University of Sydney:—B.E. degree (in the Department of "Civil" or "Mechanical and Electrical" Engineering).

Messrs. E. R. Briggs, H. Duncan, F. C. R. H. Boyd, and D. J Morris have especially distinguished themselves in the Associate

Membership Examinations, the latter two gaining the Bayliss Prizes for the year, under the conditions of that award.

The qualifications of candidates for transfer to full membership is a subject of much concern to the Council, who have found with regret that a rather large number of those whose papers have come before them during the Session cannot yet claim such responsible experience or professional eminence as to justify transfer. The Council do not doubt that the members generally will share their view that the disappointment caused by the rejection of premature recommendations for transfer is not too great a price to pay for the maintenance of the highest standard of qualification for full membership of The Institution.

With regard to the educational work of the Council, it is satisfactory to record that the Students Associations continue to improve in activity and efficiency.

The Yarrow Educational Fund, which is now in systematic operation under the direction of a Special Committee, is supplying the means of training (practical or scientific) to eight deserving Scholars (Appendix II, p. 246). The resources of the Fund admit of the appointment of two or three new Scholars in each year; and it has been most gratifying to the Committee to observe the earnestness and ability of the Candidates who come before them. The Palmer Scholarship, held by Mr. Norman Scorgie for the past 4 years at the University of Cambridge, will become vacant in September, and applications for nomination to this Scholarship are now invited.

The Council have accepted the administration of two Funds hitherto appropriated to the reward of merit among students of the lately closed Royal Indian Engineering College. The condition attached to the trust, which the Council have decided to term the Indian Fund, is that the income be applied to promote the efficiency of Civil Engineering in India.

The Council have had the satisfaction of nominating, for the third year in succession, Sir Guilford Molesworth, K.C.I.E., as a member of the Selection Committee in respect of appointments of Assistant Engineers in the Public Works Department of India. They have also had pleasure in nominating Sir William H. White as a representative on the Court of Governors of the University of Sheffield; Sir John Wolfe Barry as a representative on the General Board and Executive Committee of the National Physical Laboratory; and the President, Sir Alexander Kennedy, as a representative on the occasion of the celebration of the centenary of the Geological Society of London to be held in September next.

In other ways The Institution has continued to render service

in matters of public and scientific interest. Its representation upon, and the assistance given through its members to, various public inquiries is extensive; whilst the accommodation afforded freely in its premises to cognate bodies, and to others whose work is indirectly associated with its objects, has brought up to a total of 186 the meetings provided for in the rooms of The Institution during the Session.

The Roll.

The total Roll of The Institution on the 31st March, 1907, stood at 8,363; the changes which took place in it during the financial year ended on that day being shown in the accompanying Table:—

—	1 April, 1905, to 31 March, 1906.						1 April, 1906, to 31 March, 1907.					
	Honorary Members.	Members.	Associate Members.	Associates.	Students.	Totals.	Honorary Members.	Members.	Associate Members.	Associates.	Students.	Totals.
Numbers at commencement	20	2249	4117	270	1207	7863	20	2292	4187	267	1302	8068
Transferred to Members	..	88	88	..	..		..	53	53	..	..	
Elections	..	35	257	9	..		..	20	287	12	..	
Admissions	..	..	..	..	334	645	..	..	..	..	370	702
Restored to Register	..	2	7	1	..		..	5	7	1	..	
Deceased	..	59	42	4	5		1	51	36	11	1	
Resigned	..	20	25	7	13		..	13	29	5	13	
Erased	..	3	39	2	6		..	8	31	1	10	
Elected Associate Members	..	..	..	..	71	440	..	..	..	..	76	407
Removed—over age	..	..	..	..	144	205	..	..	..	..	121	295
Numbers at termination	20	2292	4187	267	1302	8068	19	2298	4332	263	1451	8363

The elections comprised 20 Members, 287 Associate Members, and 12 Associates; 370 candidates were admitted as Students, and the names of 5 Members, 7 Associate Members and 1 Associate were restored to the register. From this addition of 702 must be deducted the deaths, resignations and erasures during the year, the Students elected Associate Members, and those who, having passed the age-limit of that class, ceased to be attached to The Institution, amounting in all to 407, leaving a net increase of 295. At the date of this Report, the total Roll of The Institution is 8,445.

Among the deceases, the Council record with especial regret those of Viscount Goschen, Honorary Member, Mr. Francis William Webb, Vice-President, and Sir Edward James Reed, K.C.B., former Member of Council.

The full list of deceases is as follows:—

Honorary Member.—*Viscount* Goschen, P.C.

Members.—Charles Sneath Allott; Imrie Bell; Joseph Bernays; Carl Roderique Louis Menni Bonn; John Richard Brittle; Robert Chapman; Hugh Mortimer Herbert Collier; John James Robertson Croes; William Crozier; William Cudworth; James Dredge, C.M.G.; Thomas Dyke; *Cavaliere* John Elliott; John Devonshire Ellis; Richard Gervase Elwes; James Richard Fletcher; Charles Benjamin Graham; William Silver Hall; Arthur James Hamilton-Smythe; Robert Nathaniel Hodges; Alexander Lauder Hogg; John Hawkins; Darnton Hutton; George Cecil Kenyon; Joseph Lindley; Hugh Unsworth McKie; Francis John Charles May; Vitale Domenico de Michele; Joseph Newey; Jacques Augustin Normand; Charles Edward Perry; James Perry; Edward Purser; Alan Railton; *Sir* Edward James Reed, K.C.B.; James Rowan; Frederick Sharp; Carl Siemens; Josiah Timmis Smith; James Lindsay Stirling; John Stirrat; Frederic James Ramsbottom Sutcliffe; John Edward Tanner, C.M.G.; Joseph Helen Thornhill; William Edwin Thursfield; Illius Augustus Timmis; Francis William Webb; Richard Flint Welby; Henry Hartley West; Arthur Henry Whipham; James Young.

Associate Members.—Percy Leonard Addison; George Robert Bale; Joseph William Barker; Alfred George Bessemer, junr.; James MacLellan Blair; Charles Robert Dudley Borrett; Leonard Brereton; William Richard Hopkins Chipperfield; Henry Dennis; Robert Downing; John Foley; James Henry Frogley; Charles Henry Grant; Thomas Percy Gunyon; Jonathan Haigh; William Henry Hopkinson; Andrew Howatson; Gerald Edwin Hull; Charles Johnston; John Charles Lewis Loeffler; John Maclean; Richard Henry Middleton; Koichi Murakami; George Brown Murdoch; John Murray; Francis James Odling; Magnus Ohren; Herbert Walter Prince; John Newman Robinson; Henry George Archibald Rouse; Louis Charles de Rozario; William Edwards Shaw; William Simpkins; Eugene Horace Trery; Samuel Sugden Waddington; Julian Stanton Wise.

Associates.—Charles Denton Abel; Claude Baggallay, K.C.; Charles John Brydges; *General* Rafael Cerero y Saenz, *Spanish Royal Engineers;* Robert George Clutton; *Major-General* William Henry Edgcome, R.E. *ret.*; Philip Hedger; John Mathieson; Patrick Ogilvie; William Thomas Sugg; John Thomson.

The following resignations have been received:—

Members.—Henry Oakden Fisher; Charles Edward Gael; Charles Good; William Hughes; Daniel Francis Martin; Amyas Morse; Jonathan Packman; Charles George Palmer; Edmund Caswell Bowyer Smyth; Herbert George Sumner; Thomas William Traill; Francis Henry Trevithick; Berkeley Deane Wise.

Associate Members.—William Milward Allen; Wilfred Bailey; Ernest Augustus Brine; Frank Bullock; Sulyarde Bernard Cary; William Chadwick; Edgar Stirling Cobbold; Charles Alfred Craven; Edward Houtson Elsworthy; John Cunningham Ford; George Leopold Gregson; Evelyn Llewellyn Hustler Jones;

George Arthur Jones; Benjamin Kitt; George Edwin James McMurtrie; John Clarkson Philips Maynard; James Parkinson; Herbert Edgar Peck; Herbert Phillips; Samuel Matthew Pipe; John James Potts; Acheson Lyle Rathbone; Louis Edgar Roberts; David William Ross; William Salmond; Ernst George Angantyr Schéle; Charles Thornton Rennie Scovell; Lightly Stapleton Simpson; Wilhelm Willink.

Associates.—George Copus; George Brown Godfrey; *Major* Francis Ignacio Ricarde-Seaver; *Lieut.-General Sir* Richard Hieram Sankey, R.E. *ret.*, K.C.B.; Henry Cecil Travers.

Finance.

The Statements of Accounts for the year ending the 31st March, 1907, duly audited, will be found at pp. 238–45.

The receipts on Income Account amounted to £26,755 18*s.* 7*d.*, as against £26,092 5*s.* 11*d.* last year; on Capital Account (admission-fees and life-compositions) £3,436 13*s.*; from Trust Funds, £816 16*s.*; the total receipts being £31,009 7*s.* 7*d.*, exclusive of £3,648 3*s.* 11*d.* received for the purposes of the Engineering Standards Committee. The receipts on Income Account included subscriptions £21,153 3*s.*, dividends £2,328 9*s.*, and rents £677 4*s.*

The expenditure on Income Account was £26,476 16*s.* 7*d.*, exclusive of £3,500 paid over to the Engineering Standards Committee. It included some considerable items of extraordinary expense in connection with the Students' Associations, the Library and Publications, and a fifth donation of £500 to the National Physical Laboratory.

The expenditure on Trust Funds account amounted to £750 17*s.* 2*d.*

The nominal value of the investments on Institution account was £79,300, purchased for £79,520 2*s.* 2*d.*; and on Trust Funds account £29,116 4*s.* 9*d.* (nominal value). This is exclusive of the sum of £1,133 10*s.* 3*d.*, the value of the recently acquired Indian Fund, which is not yet invested. The present mean market value of the Institution investments is £73,501.

No investment has been made on Capital Account, but the sum of £10,000, on deposit with the Bankers, is carried forward as part of the cash balance, that disposition of the money being regarded as the most satisfactory course at the present time.

Meetings.

The Ordinary Meetings held during the Session numbered twenty-two, of which twenty-one were devoted to the consideration of fifteen Original Communications, the Inaugural Meeting being occupied by

the President's Address to the members. The subjects discussed have as usual illustrated the wide range of Civil Engineering as defined by the Charter, and interpreted in the practice of The Institution. The Papers dealt with during any Session may be regarded as reflecting generally the nature of the subjects and problems which for the time being occupy a leading place in the minds of engineers; and herein lies, no doubt, the explanation of the fact that five of the Papers of the past Session dealt with the application of electricity to various branches of engineering work; and that other three of them are devoted largely to the development and use of the internal-combustion motor. Of these three, one by Col. R. E. B. Crompton dealt with "Modern Motor-Vehicles," a subject which at the moment is of almost universal interest, and the other two were respectively "Internal-Combustion Engines for Marine Purposes," by Mr. J. T. Milton; and "On the Limits of Thermal Efficiency in Internal-Combustion Motors," by Mr. Dugald Clerk. The latter contained a critical examination and analysis of some of the data obtained in the gas-engine trials made by the Institution Committee on Standards of Efficiency of Internal-Combustion Engines. The Papers referred to as being of an electrical character were the following:—"Single-Phase Electric Traction," by Mr. C. F. Jenkin; "Mechanical Considerations in the Design of High-Tension Switch-Gear," by Mr. H. W. E. Le Fanu; "The Construction of Overhead Electric Transmission-Lines," by Mr. A. P. Trotter; "The Application of Hydro-Electric Power to Slate-Mining," by Mr. M. Kellow; and "Electrically-Driven Winding-Gear and the Supply of Power to Mines," by Mr. A. H. Preece. Mr. Jenkin's Paper described the advances in single-phase traction which have been made since 1902, and corroborated the conclusion arrived at by Messrs. Mordey and Jenkin in their Paper contributed to The Institution in that year, namely, that single-phase working was the most suitable for general railway-traction on English lines. Mr. Trotter dealt with the problems that are arising in this country in connection with the transmission of electrical energy over considerable distances, and submitted for discussion and criticism, by permission of the Board of Trade, a draft model description of overhead-line construction for high pressures. The nature of the other three Papers is concisely indicated by their titles. As regards constructional work, three bridges have been described, namely, "The Victoria Falls Bridge," by Mr. G. A. Hobson; "Swing-Bridge over the River Avon at Bristol," by Mr. W. H. B. Savile; and "The Pyrmont Bridge, Sydney, N.S.W."

by Mr. Percy Allan. Mr. Hobson's Paper described the construction of a two-hinged spandrel-braced steel arch of 500 feet span, across the gorge below the Victoria Falls of the Zambezi River. Apart from the rapidity and success with which the work was carried out at so great a distance from the resources of civilized countries, and under the natural difficulties of the site, the æsthetic features of the design met with general commendation. The greatest undertaking described in any of the Papers read during the Session was the Simplon Tunnel, upon which a Paper was contributed by Mr. Francis Fox, who was the English member of a special international commission of three engineers appointed to advise the President of the Swiss Republic upon the scheme for the tunnel. The subject of water-supply was dealt with in three Papers, which were discussed together, namely, "The Talla Water-Supply of the Edinburgh and District Waterworks," by Mr. W. A. P. Tait; "Repairing a Limestone-Concrete Aqueduct," by Mr. M. R. Barnett; and "The Yield of Catchment-Areas," by Mr. E. P. Hill. The last Paper urged the importance of more thorough and systematic collection and publication of the data needed for the design of waterworks, and suggested means whereby this object might be attained.

The Council desire to record their cordial thanks to their colleague, Col. R. E. B. Crompton, for the Paper contributed by him.

For some of the Papers read the Council have awarded Medals or Premiums to Messrs. Dugald Clerk, J. T. Milton, G. A. Hobson, C. F. Jenkin, W. A. P. Tait, A. P. Trotter and M. Kellow.

These awards, as well as those which will be made in the Autumn in respect of the Papers to be published in Section II of the Proceedings, will be presented at the opening meeting of the next Session.

Students' Meetings and Visits to Works.

During the Session nine Students' Meetings have been held in London. At that held on the 12th April, Mr. Richard W. Allen, Assoc. M. Inst. C.E., delivered an interesting and instructive lecture, illustrated by lantern-slides, detailing his observations during a recent visit to Canada and Japan; and at the remaining meetings eight Students' Papers have been read and discussed.

Including the work of the Associations of Students in the Provinces, all of which it is gratifying to find are in a flourishing condition, twenty-eight Papers have been read by Students during the Session, nineteen of which are submitted in competition for Miller prizes. The customary series of visits to engineering works have been made during the Session, both in London and in the six

provincial centres. The Students' Thirty-second Annual Dinner in London was held on the 17th April.

Both in respect to the meetings and the visits to works in London, the attendance does not compare favourably with that of recent years. The Council would urge upon members the desirability of influencing Students with whom they come into contact to avail themselves more fully of the educational advantages afforded by The Institution to that class.

The "James Forrest" Lecture.

As customary, allusion should be made here to the "James Forrest" Lecture, which has been usually delivered during the Session. This year it is proposed that the lecture be given at the time of the Engineering Conference; the date fixed being Tuesday, the 18th June, when Dr. F. Elgar, F.R.S., will discourse upon unsolved problems in the design and propulsion of ships.

The Library.

The Subject-Catalogue for the period 1895 to 1904, prepared by the Superintendent, completes the Library Catalogue to that date. The entire Catalogue to 1904, consisting of four volumes of Authors and three of Subjects, may be obtained by members on payment of the printing and binding charges, which amount to 4*s.* per volume. Additions since 1904 are recorded, both as regards Authors and Subjects, by means of printed card-files, available for reference in the Library; and Supplemental Catalogues will be prepared and published at regular intervals in future, as required.

During the year the remaining books which needed attention have been rebound or repaired, and the condition of the entire contents of the Library is now satisfactory in that respect.

The general stock-taking of the books begun last year is being carried on without hindrance to the use of the Library by members, although its rate of progress is necessarily slow. It is expected that it will be completed by the end of this year.

On fifty-two evenings during the Session, on which meetings of The Institution or of other Societies have taken place, the Library has been open continuously until 10 o'clock, thus offering considerable opportunity of using it, to those who are unable to do so during the day. Notice of these dates was posted as usual in the Library and in the Hall.

A Subject-Index to Vols. cxix-clxx of the Minutes of Proceedings, covering the period 1894 to 1907 inclusive, is in course of preparation, and, it is hoped, will be ready for publication next year. On its completion a Name-Index for the same period will be taken in hand.

Conference.

As mentioned in the last Report, it is proposed to hold the Fourth Engineering Conference this year, the time fixed being the 19th, 20th, and 21st June. The Sectional Committees have been formed, and the organization and preliminary arrangements are already in an advanced condition. The business of the Conference will be transacted in the Institution rooms, and in the meeting-room of the Surveyors' Institution opposite, kindly placed at the Council's disposal for the purpose. The Annual Conversazione will take place at the Royal Albert Hall, under conditions which will admit of the entertainment being held on one evening—that of the 20th June.

Portraits.

The collection of portraits has been added to by the acquisition from Mrs. W. Scott Peat of a painting of the late George Parker Bidder, Past-President; and by the gift from Sir Alexander Binnie, Past-President, of his portrait, painted by Sir George Reid.

[Appendixes.

APPEN

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£ s. d.	£ s. d.
To Balance, 1 April, 1906, viz. :—		
On Deposit	6,000 0 0	
Cash in the hands of the Treasurer :—		
Current Account	2,413 17 7	
No. 2 Account	461 3 10	
Cash in the hands of the Secretary	8 10	
		8,875 10 3

INCOME.

		£ s. d.	£ s. d.	£ s. d.
— Subscriptions received :—				
	Arrears, prior to 1 January, 1906	572 15 0		
	For the year 1906	6,214 7 6		
	For the year 1907	14,343 19 6		
	Advance	22 1 0		
			21,153 3 0	
— Minutes of Proceedings :—Repayment for Binding, &c.			558 0 6	
— Library Fund			301 12 6	
— Dividends : 1 year on				
£		*Institution Dividends.*		
10,000	2½% Consols	237 10 0		
9,400	London County 3% Stock	267 18 0		
4,000	Manchester Corporation 3% Stock	114 0 0		
6,000	Metropolitan 3½% Stock	199 10 0		
3,000	Metropolitan Water Board 3% Stock	85 10 0		
6,000	Great Eastern Railway 4% Debenture Stock	228 0 0		
8,000	Great Northern Ry. 3% Debenture Stock	228 0 0		
8,000	Great Western Ry. 4% Debenture Stock	304 0 0		
8,000	Lancs. & Yorks. Ry. 3% Debenture Stock	228 0 0		
7,300	London & N.W. Ry. 3% Debenture Stock	208 1 0		
9,600	Midland Ry. 2½% Debenture Stock	228 0 0		
			2,328 9 0	
£79,300	Nominal or par value			
— Refund of Income Tax to 5 Apr. 1906			114 9 0	
— Rents—No. 27 Great George Street			677 4 0	
— Examination Fees			1,454 5 0	
— Interest on Deposit			132 17 7	
— Internal-Combustion Engines Committee (Returned)			34 2 0	
— Council Dining Club			1 16 0	
				26,755 18 7
	Carried forward			£35,631 8 10

DIX I.

from the 1st APRIL, 1906, *to the* 31st MARCH, 1907.

EXPENDITURE.

Cr. GENERAL EXPENDITURE.

	£	s.	d.	£	s.	d.	£	s.	d.
By House and Establishment Charges :—									
Repairs :—General	197	6	3						
No. 27 Gt. George St.,	106	19	4						
				304	5	7			
Rent of No. 27 Great George Street				600	0	0			
Rates and Taxes :—The Institution	1,168	6	8						
No. 27 Gt. George St.	245	14	7						
				1,414	1	3			
Insurance :—The Institution	95	4	9						
No. 27 Gt. George St.	3	0	0						
				98	4	9			
Fixtures and Furniture				378	8	3			
Lighting, Warming and Ventilating :—									
The Institution	425	14	1						
No. 27 Gt. George St.	18	3	9						
				443	17	10			
Charges for Water (including lifts), Rent of Telephone, &c.	100	17	0						
Charges for Water, No. 27 Great George Street	20	11	0						
				121	8	0			
Refreshments at Meetings				82	2	9			
Assistance at Meetings				34	17	0			
Students' Meetings and Grants to Students' Associations (including refreshments), Donation to Annual Dinner, and Visits				1,110	12	0			
Household Expenses				635	10	3			
							5,223	7	8
— Postages, Telegrams, and Parcels				427	13	7			
— Stationery and Printing				1,135	16	3			
— Diplomas				22	17	0			
— Watt Medals				14	0	0			
— Stephenson Medals				28	0	0			
— Inscription on Joule Medal					13	6			
— Annual Dinner (Balance 1906 and part 1907)				273	17	11			
— Conversazione (1906 and part 1907)				1,138	7	2			
— Engineering Conference, 1907				99	7	2			
— Milan Exhibit				199	5	11			
							3,339	18	6
— Salaries				3,350	0	0			
— Clerks, Messengers, and Housekeeper				1,775	3	10			
— Retiring Allowances and Donations				1,824	10	0			
							6,949	13	10
— Library :—Books and Periodicals				269	0	11			
Binding				574	6	5			
Author-Catalogue 1895–1904				273	6	4			
							1,116	13	8
Carried forward							£16,629	13	8

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*continued.*

Dr.	£ s. d.	£ s. d.
Brought forward		35,631 8 10
To Engineering Standards Committee :—		
— Balance in hands of Treasurer, 1 April, 1906 .	1,325 12 10	
— Received from Board of Trade in respect of Grant	500 0 0	
— Subscriptions	1,813 10 0	
— Amount received from Committee on account of Sale of its Publications	1,326 16 10	
— Interest on Deposit	7 17 1	
	4,973 16 9	
Deduct Payments to the Engineering Standards Committee	3,500 0 0	
— Balance in hand 31 March, 1907		1,473 16 9

Capital.

To Admission-Fees	3,373 13 0	
— Life-Composition	63 0 0	
		3,436 13 0

Trust Funds Income.

Telford Fund.

To Dividends :—1 year on

£ s. d		£ s. d.	£ s. d.	£ s. d.
5,439 11 0	2½% Consols		129 3 8	
3,299 2 0	Ditto (Unexpended Dividends) . .		78 7 4	
	Refund of Income Tax, to 5 Apl. 1906		10 18 4	
£8,738 13 0			218 9 4	
	Manby Donation.			
£250 0 0	Great Eastern Ry. 4% Irredeemable Guaranteed Stock	9 10 0		
	Refund Income Tax . .	10 0		
			10 0 0	
	Miller Fund.			
3,125 0 0	2½% Consols	74 4 8		
2,004 17 5	Ditto (Unexpended Dividends)	47 12 4		
	Refund Income Tax . .	6 8 0		
£5,129 17 5			128 5 0	
	Carried forward		356 14 4	£40,541 18 7

from the 1ST APRIL, 1906, *to the* 31ST MARCH, 1907.

EXPENDITURE—*continued.*

Cr.	£ s. d.	£ s. d.
Brought forward		16,629 13 8
By Publications :—		
"Minutes of Proceedings," Vols. clxiii, clxiv, clxv, clxvi, and Vol. clxvii	7,745 19 6	
Charters, By-Laws, and Lists of Members	408 6 8	
		8,154 6 2
— Professional Auditor's Fee	105 0 0	
— Legal Expenses	19 19 9	
— Examinations	950 17 6	
— Donation to Westminster Hospital	10 10 0	
— Contribution to the Expenses of the National Physical Laboratory	500 0 0	
— Expenses of Committee on Training of Engineers	67 16 3	
— Advisory Committees	38 13 3	
		1,692 16 9
		26,476 16 7

TRUST FUNDS.

	£ s. d.	£ s. d.	
By Telford Premiums :—			
Balance 1904–5	32 15 9		
1905–6	198 18 5		
— Telford Medals	45 5 0		
		276 19 2	
— Manby Premium		13 8 0	
— Miller Prizes	57 12 4		
— Miller Scholarship	40 0 0		
		97 12 4	
Carried forward		£387 19 6	£26,476 16 7

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

Dr.	RECEIPTS—*continued.*		£ s. d.	£ s. d.
	Brought forward . .		356 14 4	40,541 18 7
	TRUST FUNDS—*continued.*			
	Howard Bequest.			
£551 14 6	2½% Consols	13 2 0		
	Refund Income Tax . .	13 8	13 15 8	
	Trevithick Memorial.			
£103 0 0	2½% Consols	2 9 0		
	Refund Income Tax . .	2 8	2 11 8	
	Crampton Bequest.			
£512 15 11	2½% Consols	12 3 4		
	Refund Income Tax . .	13 0	12 16 4	
	"James Forrest" Lecture and Medal Fund			
£372 0 0	South-Eastern Ry. 5% Debenture Stock . . .	17 13 4		
	Refund Income Tax . .	18 8	18 12 0	
	Palmer Scholarship.			
1,381 1 6	Metropolitan 3% Stock .	39 7 4		
115 4 7	Ditto (Unexpended Dividends)	3 5 8		
	Refund Income Tax . .	2 4 8	44 17 8	
£1,496 6 1				
	John Bayliss Bequest.			
£1,013 17 10	London County 3% Stock	28 18 0		
	Refund Income Tax . .	1 10 4	30 8 4	
	Yarrow Educational Fund.			
6,728 0 0	Midland Ry. 2½% Preference Stock . . .	159 15 10		
4,220 0 0	North Eastern Ry. 4% Preference Stock . .	160 7 2		
	Refund Income Tax . .	16 17 0	337 0 0	
				816 16
£10,948 0 0				
	TRUST FUNDS. CAPITAL.			
	Investments and Cash transferred to the Institution on the closing of the Royal Indian Engineering College—			
	Former Coopers Hill Trust.			
	Rs.14,000 Indian Govt. 3½% Loan 1865 (since realized) and £12 8*s.* in Cash		12 8 0	
	Former O'Callaghan Medal Fund Cash for investment		209 18 11	
				222 6 1
				£41,581 1

from the 1ST APRIL, 1906, *to the* 31ST MARCH, 1907.

EXPENDITURE—*continued*.				£	s.	d.	£	s.	d.
Cr. Brought forward .				387	19	6	26,476	16	7
TRUST FUNDS—*continued*.									
By "James Forrest" Lecture (fourteenth)	15	16	7						
— James Forrest Medal	2	15	0						
				18	11	7			
— Palmer Scholarship—									
1 year's dividend, etc., to Scholar . . .				44	17	8			
— Bayliss Prizes				30	0	0			
— Yarrow Scholarships				269	8	5			
							750	17	2
							27,227	13	9
— Balance, 31 March, 1907, viz. :—									
Engineering Standards Committee							1,473	16	9
On Deposit				10,000	0	0			
Cash in the hands of the Treasurer :—									
Current Account				2,342	5	8			
No. 2 „				528	15	5			
Cash in the hands of the Secretary . . .				8	9	11			
							12,879	11	0
							£41,581	1	6

STATEMENT OF INVESTMENTS HELD 31 MARCH, 1907.

Institution Investments.

£			£	s.	d.	£	s.
10,000	2½% Consols	Cost	9,286	17	1		
9,400	London County 3% Stock	„	9,025	9	6		
4,000	Manchester Corporation 3% Stock .	„	4,085	1	0		
6,000	Metropolitan 3½% Stock	„	6,517	15	0		
3,000	Metropolitan Water Board 3% Stock	„	2,958	16	0		
6,000	Great Eastern Railway 4% Debenture Stock	„	7,749	18	3		
8,000	Great Northern Railway 3% Debenture Stock	„	7,642	16	4		
8,000	Great Western Railway 4% Debenture Stock	„	10,547	5	0		
8,000	Lancashire and Yorkshire Railway 3% Debenture Stock	„	7,452	14	8		
7,300	London and North Western Railway 3% Debenture Stock	„	6,792	10	5		
9,600	Midland Railway 2½% Debenture Stock	„	7,460	18	11		
79,300						79,520	2
	Original cost of the freehold of the Institution Premises and of the New Building, including buildings now removed . . .					124,379	10

Note.—No value has been attached, for the purpose of this statement, to the Books, Furniture, Fittings, Pictures, &c., in the Institution Building.

Trust Funds Investments.

Telford Fund.

£	s.	d.			
1,945	19	0	2½% Consols—Acquired with a bequest of . . .		2,000 0
3,479	12	9	do.	Converted from Government Stocks bequeathed	Bequest
13	19	3	do.	Purchased with bonus on conversion cost	13 11
5,439	11	0			
3,299	2	0	do.	Purchased with unexpended dividends	3,034 18
8,738	13	0			

Manby Donation.

250	0	0	Great Eastern Railway 4% Irredeemable Guaranteed Stock	Donatio

Miller Fund.

3,125	0	0	2½% Consols—Acquired with a bequest of . . .		3,000 0
2,004	17	5	do.	Purchased with unexpended dividends	1,850 2
5,129	17	5			

TRUST FUNDS INVESTMENTS—*continued.*

Howard Bequest.

£	s.	d.		£	s.	d.
551	14	6	2½% Consols—Acquired with a bequest of . . .	500	0	0

Trevithick Memorial.

103	0	0	2½% Consols—Acquired with a presentation of . .	100	0	0

Crampton Bequest.

512	15	11	2½% Consols—Acquired with a bequest of . . .	500	0	0

"James Forrest" Lecture and Medal Fund.

320	0	0	South Eastern Railway 5% Debenture Stock Acquired with a subscription of	510	0	0
52	0	0	Ditto Acquired with a subscription of £93 14*s.* 8*d.* and 19*s.* 4*d.* cash	94	14	0
372	0	0				

Palmer Scholarship.

1,381	1	6	Metropolitan 3% Stock bequeathed	Bequest.		
115	4	7	Ditto purchased with unexpended dividends . .	132	18	0
1,496	6	1				

John Bayliss Bequest.

1,013	17	10	London County 3% Stock Acquired with a bequest of	1,000	0	0

Yarrow Educational Fund.

6,728	0	0	Midland Railway 2½% Preference Stock	10,049	9	6
4,220	0	0	North Eastern Railway 4% ditto . . . . . . (Acquired with a gift of £10,000 and £49 9*s.* 6*d.* interest thereon.)			
10,948	0	0				

The Indian Fund.

(Formerly comprised in the Coopers Hill Trust and the O'Callaghan Medal Fund.)

Rs.14,000 Indian Government 3½% Loan 1865 (since realized) and £222 6*s.* 11*d.* in Cash—*to be invested.*

J. H. T. TUDSBERY, *Secretary.*

30 *April*, 1907.

Examined with the Books and Securities and found correct.

PERCIVAL D. GRIFFITHS, F.C.A., } *Auditors.*
JAMES M. DOBSON.

APPENDIX II.

YARROW EDUCATIONAL FUND.

AWARD OF SCHOLARSHIPS, 1906–7.

Name of Scholar.	Date of Award.	Particulars of Scholarship.
Carty, Edward George . .	30 Jan. 1906	£70 per annum for 3 years fro 1 January, 1906.
Kennett, William Charles .	"	£70 per annum for 3 years fro 1 July, 1906.
Webb, Albert Edwin . . .	"	£70 per annum for 3 years fro 1 January, 1907.
Rowell, Henry Snowden . .	18 Dec. 1906	£30 per annum for 3 years fro 1 January, 1907.
Wishart, George	"	£60 in six quarterly payments £10 from 1 January, 1907.
Dawson, Lionel Edward . .	"	£60 per annum for 2 years fro 1 January, 1907.
Lees, George	26 Feb. 1907	£45 in six quarterly payments £7 10*s*., from 1 January, 190
Bullock, William Edward .	"	Subject to settlement in tl autumn.

MEDALS AND PREMIUMS AWARDED FOR THE SESSION 1905–1906, AND PRESENTED ON THE 6TH NOVEMBER, 1906.

FOR PAPERS READ AND DISCUSSED AT THE ORDINARY MEETINGS.

1. A Telford Gold Medal to John Arthur Saner, M. Inst. C.E., for his Paper "On Waterways in Great Britain."
2. A Watt Gold Medal to George Gerald Stoney, M. Inst. C.E., who, jointly with the Hon. Charles Algernon Parsons, C.B., F.R.S., Member of Council, presented the Paper on "The Steam-Turbine."
3. A George Stephenson Gold Medal to Thomas Ernest Stanton,[2] D.Sc., M. Inst. C.E., and a Telford Premium to Leonard Bairstow, for their joint Paper "On the Resistance of Iron and Steel to Reversals of Direct Stress."
4. A Telford Premium to Harry Shelford Bidwell, M. Inst. C.E., for his Paper on "The Outer Barrier, Hodbarrow Iron Mines, Millom, Cumberland."
5. A Telford Premium to John James Webster,[1 2] M. Inst. C.E., for his Paper on "The Widnes and Runcorn Transporter-Bridge."
6. A Telford Premium to Cathcart William Methven, M. Inst. C.E., for his Paper on "The Harbours of South Africa; with special reference to the Causes and Treatment of Sand-Bars."
7. A Telford Premium to Henry Alexander Mavor, M. Inst. C.E., for his Paper on "Heat-Economy in Factories."
8. A Telford Premium to Sir Frederick Robert Upcott, K.C.V.O., C.S.I., M. Inst. C.E., for his Paper on "The Railway-Gauges of India."
9. A Manby Premium to David Ernest Lloyd-Davies,[3] Assoc. M. Inst. C.E., for his Paper on "The Elimination of Storm-Water from Sewerage Systems."

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[1] Has previously received a Telford Medal.
[2] Has previously received a Telford Premium.
[3] Has previously received a Miller Prize.

For Papers Printed in Section II. of the Proceedings for the Session 1905–1906.

1. A Telford Gold Medal to George Alfred Denny, Assoc. M. Inst. C.E., for his Paper on "Design and Working of Gold-Milling Equipment, with special reference to the Witwatersrand."
2. A George Stephenson Gold Medal to William Ernest Dalby, M.A., B.Sc., M. Inst. C.E., for his Paper on "The Economical Working of Locomotives."
3. A Telford Premium to William Ralph Baldwin-Wiseman, M.Sc., Assoc. M. Inst. C.E., for his Paper on "The Flow of Underground Water."
4. A Telford Premium to George Neill Abernethy, M. Inst. C.E., for his Paper on "The Midland Railway Company's Harbour at Heysham, Lancs."
5. A Telford Premium to Henry Robert Cecil Blagden for his Paper on "The Filtration-Works for supplying the Town of Alexandria with Potable Water."
6. A Telford Premium to Michael Richard Collins, Assoc. M. Inst. C.E., for his Paper on "Irrigation in the Transvaal."
7. A Telford Premium to James Kelly, Assoc. M. Inst. C.E., for his Paper "On the Raising of Water by Compressed Air, at Preesall, Lancashire."
8. A Crampton Prize to Percy Tillson Gask, M. Inst. C.E., for his Paper on "The Construction of the Seaham Harbour Dock-Works."

For Papers Read before Meetings of Students in London and at the Provincial Associations.

1. The "James Forrest" and the "James Prescott Joule" Medals and a Miller Prize to Arnold Frean Harrison, B.Sc., Stud. Inst. C.E. (Manchester), for his Paper on "The Modern Steam-Turbine."
2. A Miller Prize to Ralph Freeman, Stud. Inst. C.E. (London), for his Paper on "The Design of a Two-Hinged Spandrel-Braced Steel Arch."
3. A Miller Prize to Arthur John Grinling, Stud. Inst. C.E. (Birmingham), for his Paper on "Permanent-Way Construction and Maintenance."
4. A Miller Prize to Thomas Reginald Grigson, Stud. Inst. C.E. (London), for his Paper on "Prince of Wales's Pier, Falmouth."

5. A Miller Prize to James Dudley Ward Ball, Stud. Inst. C.E. (Manchester), for his Paper on "Transition Curves for Railways and Tramways."
6. A Miller Prize to Arnold Morris, Stud. Inst. C.E. (Manchester), for his Paper on "Bacterial Sewage Purification."

Bayliss Prize.

Bayliss Prizes, awarded on the results of the October and February Examinations 1905–1906 respectively, to Fitzroy Tozer Chapman, B.Sc., and Charles Antony Ablett, Studs. Inst. C.E.

The Council find that Robert Somerville Bayntun and Edwin Donald McQueen, Assoc. MM. Inst. C.E., and Edwin Samuel Crump, Stud. Inst. C.E., deserve honourable mention in connection with the aforesaid Examinations respectively

ORIGINAL COMMUNICATIONS

RECEIVED BETWEEN 1 APRIL, 1906, AND 31 MARCH, 1907.

AUTHORS.

Adams, B. K. No. 3,667.—The Floating-out of a Railway Bridge over the River Don at Conisborough. With 4 Diagrams and 5 Photographs.

Aldersmith, C. H. No. 3,709.—Investigation into the Behaviour of Hollow Steel Columns under Compression with a view to discovering the most efficient Cross-section.

Barton, E. G. No. 3,656.—Description of Pontoon Bridges for Road Traffic over Rivers in Darbhanga District in Bengal. With 4 Drawings.

Batho, E. No. 3,713.—The Temperature Gradient in De Laval Steam Nozzles. With 8 Diagrams.

Beard, E. T. No. 3,657.—The New Approach Road, Marine Drive and Seawall, Scarborough. With 12 Tracings and a Map.

Braine, C. D. H. No. 3,715.—Influence of Forests on Natural Water Supply. With 2 Photographs.

Brightmore, A. W. No. 3,679.—Loss of Pressure in Water flowing through Straight and Curved Pipes. With 8 Diagrams.

——————. See Ottley.

Carnegie, D., and F. M. Osborn. No. 3,700.—Recent Developments in the Manufacture of Crucible Cast Steel. With 11 Drawings.

Carus-Wilson, C. A. No. 3,686.—The Predetermination of Train Resistance. With 2 Diagrams and 8 Blue-prints.

Clerk, D. No. 3,696.—On the Limits of Thermal Efficiency in Internal-Combustion Motors. With 9 Diagrams.

Copperthwaite, W. C. No. 3,670.—The New Vauxhall Bridge. With 20 Drawings.

Cox, C. L. No. 3,659.—The Efficiency of the Shone System of Sewage Pumping. With 1 Plan and 8 Tables.

Crompton, Col. R. E. B. No. 3,669.—Modern Motor Vehicles. With 9 Sunprints.

AUTHORS.

Cuffe, O. F. L. W. No. 3,644.—Survey of Inaccessible Places by Tacheometry. With 1 Photograph and 1 Tracing.

Cuthbert, J. G. No. 3,704.—Realignment of Railway Curves. With 1 Table.

Dawson, F. J. No. 3,663.—The Building of Road Bridges in the Transvaal. With 1 Drawing and 2 Photographs.

Dolby, E. R. No. 3,687.—Some Methods of Heating adopted in recently-built Hospitals and Asylums. With 18 Drawings and 19 Diagrams.

Durham, F. R. No. 3,673.—Recent Design of Cast Iron and other Pipes on the Continent. With 4 Diagrams, 2 Drawings and 5 Tables.

Eliot, W. No. 3,701.—Keyham Dockyard Extension. With 5 Tracings.

Elliot, M. No. 3,660.—Construction of Horizontal Arched Dam, Violet Town Waterworks. With 2 Tracings.

Ellis, S. H. No. 3,649.—The Tranmere Bay Development Works. With 8 Drawings.

Fedden, S. E. No. 3,654.—Pressure Regulation on Low Tension Alternating Current Networks, with a description of the Water Lane Switching and Transforming Station of the Sheffield Corporation Electric Supply Department. With 3 Drawings.

Fox, F. No. 3,651.—The Simplon Tunnel. With 23 Drawings.

Francis, J. No. 3,714.—Competition for Water Sources (The New River Venture). With 2 Plans and 8 Tracings.

Frech, S. A. No. 3,646.—The Tredegar Dry Dock, Newport, Mon. With 6 Tracings.

Gibson, A. H. No. 3,648.—The Analysis of Flue and Exhaust Gases. With 1 Diagram.

Gillman, G. No. 3,716.—Shipping Arrangements for Iron Ore at Aguilas (Spain). With 11 Tracings.

Goodman, J. No. 3,655.—An Experimental Investigation of the Maximum Stresses in Loaded Crane Hooks. With 8 Diagrams and 4 Photographs.

Gore, W. See Wilson.

Haggie, R. H. No. 3,682.—The Use of Electric Energy in Working Mines.

Hassard, C. No. 3,676.—Orange River Colony Relief Works. With 3 Tracings.

Heather, H. J. S., and A. M. Robeson. No. 3,711.—The Cost of

AUTHORS.

Power on some of the Producing Mines of the Witwatersrand, as determined with reference to its proposed purchase from a central source.

Herschel, C. No. 3,680.—The Venturi Water Meter: the first 20 years of its existence. With 1 Diagram, 2 Tracings and 7 Photographs.

Hill, E. P. No. 3,641.—The Yield of Catchment Areas.

Hobson, G. A. No. 3,675.—The Victoria Falls Bridge. With 10 Drawings.

Hole, W. T. No. 3,685.—Tramway Track Construction, Johannesburg. With 1 Tracing.

Hutchison, W. No. 3,640.—Some Recent Structures erected by the Canadian Pacific Railway Company at their Port on Lake Superior. With an Album of Photographs.

Jeffcott, H. H. No. 3,668.—Notes on the Design of Shafts, with special reference to High Speed Electric Generators.

Jenkin, C. F. No. 3,647.—Single-Phase Electric Traction. With 18 Diagrams, 6 Photographs, 6 Drawings and 1 Blue-print.

Jordan, W. L. No. 3,699.—The Scrapping of the First Law of Motion. With 10 Diagrams.

Ker, H. T. No. 3,688.—The Extension, Widening and Strengthening of Folkestone Pier. With 1 Chart and 6 Drawings.

Kellow, M. No. 3,650.—The Application of Hydro-Electric Power to Slate Mining. With 8 Drawings.

Kitchin, J. W. No. 3,672.—Port of Bristol: Notes on the Development of Portishead Dock for dealing with Timber. With 12 Drawings.

Lacey, J. M. No. 3,690.—Floods in Southern India. With 3 Tracings and 3 Charts.

Lambert, W. J. No. 3,694.—A proposed Method of Measuring the Extension of Tensile Test Pieces under Stress. With 4 Photographs and 1 Tracing.

Lawford, G. M. No. 3,638.—The Influence of Rugosity on the Discharge of Water-mains and Sewers.

Lewis, J. B. No. 3,710.—Some Railway Bridges on the West Coast of Tasmania. With 1 Drawing and 12 Photographs.

Lloyd, R. No. 3,643.—Megass Furnaces. With 1 Drawing.

Lloyd-Jones, C. W. No. 3,637.—The Distribution of Stress in Riveted Girders.

Matthews, E. R. No. 3,645.—American Methods of Sewer and Conduit Construction. With 1 Photograph and 1 Tracing.

AUTHORS.

Matthews, E. R. No. 3,697.—Steel-Plate Chimney Construction in Great Britain and the United States of America. With 7 Photographs, 4 Tracings and 1 Blue-print.

Milton, J. T. No. 3,678.—Internal-Combustion Engines for Marine Purposes. With 3 Drawings, 1 Tracing and 1 Sun-print.

Monro, K. N. No. 3,693.—The Practical Design of a Timber Centreing. With 1 Photograph and 1 Tracing.

Neal, R. H. B., and H. S. Newmarch. No. 3,653.—The Eastney Sewerage Works for the Drainage of Portsmouth. With 3 Tracings, 5 Drawings and 1 Photograph.

Neall, H. F. No. 3,684.—A Method of taking Soundings in an Estuary. With 1 Diagram.

Newmarch, H. S. See Neal.

Oakley, H. E. No. 3,707.—Concrete Cylinder-Sinking for Foundation of a Berthing Jetty for Battleships; with a record of frictional resistance met with. With 3 Drawings.

Ottley, Sir J. W., and A. W. Brightmore. No. 3,674.—Experimental Investigations of the Stresses in Masonry Dams subjected to Water-Pressure. With 2 Drawings.

Osborn, F. M. See Carnegie.

Phillips, E. A. W. No. 3,652.—Bond in Brickwork. With 18 Diagrams.

Preece, A. H. No. 3,698.—Electrically-driven Winding-Gear and the Supply of Power to Mines. With 6 Diagrams.

Prest, J. J. No. 3,708.—The Opening Out and Development of a large Coal Property in South-East Durham. With 14 Tracings and 1 Drawing.

Pridham, T. No. 3,712.—Notes on Water-Supply in New South Wales. With 1 Map and 2 Diagrams.

Reynolds, C. H. No. 3,717.—Notes on Reinforced Concrete. With 2 Tracings.

Rivers, E. G. No. 3,702.—Electric Heating. With 1 Tracing.

Robeson, A. M. See Heather.

Robinson, J. No. 3,691.—The New Lock at Grangemouth Docks. With 2 Drawings.

Robinson, P. J. No. 3,642.—The Stability of Chimney Shafts. With 2 Drawings.

Royal-Dawson, F. G. No. 3,671.—The Design of Wayside Stations for Single Lines of Railway. With 6 Drawings.

Savile, W. H. B. No. 3,666.—Swing-Bridge over the River Avon at Bristol. With 5 Drawings, 2 Tracings and 3 Photographs.

AUTHORS.

Sharp, A. No. 3,658.—Balancing of Multi-cylinder One-Crank Engines. With 4 Diagrams.

Smith, C. W. No. 3,677.—The Use of Steel in the Construction of Large Water Service Tanks. With 2 Drawings.

Spiller, J. W. No. 3,706.—High Speed on Railway Curves. With 3 Tracings and 1 Diagram.

Stanton, T. E. No. 3,695.—Experiments on Wind Pressure. With 11 Drawings and 2 Diagrams.

Tansley, G. E. No. 3,681.—The Heating of Air by Waste Heat. With 8 Tables, 2 Diagrams and 11 Drawings.

Thorp, R. F. No. 3,692.—Munaar Valley Central Electrical Power Scheme. With 2 Tracings.

Trotter, A. P. No. 3,703.—The Construction of Overhead Electric Transmission-Lines. With 12 Tracings, 9 Diagrams and 4 Blue-prints.

Walker, J. No. 3,689.—The North Melbourne Electric Tramways.

Weir, W. P. No. 3,639.—The Elderslie Graving Dock. With 1 Tracing.

Wilson, D. No. 3,662.—Notes on the Natal–Cape Railway, particularly with regard to the Location and Setting-out. With 3 Tracings.

Wilson, J. S., and W. Gore. No. 3,705.—Stresses in Dams: an Experimental Investigation, by means of India-Rubber Models, of the Distribution of Stress. With 29 Tracings, 37 Diagrams and 3 Photographs.

Winbolt, J. S. (the late). No. 3,664.—Theory of Equilibrium of an Arch, the materials of which it is composed being partially inelastic or their elasticity not called into play.

————————. No. 3,665. On Railway Adjusting Curves.

EXTRA MEETING.

18 June, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

The President observed that it had given the Council of The Institution very great pleasure to receive the consent of so distinguished an engineer, and one who had worked so hard in connection with The Institution itself, as Dr. Elgar, to give the fifteenth "James Forrest" Lecture, to which he was sure all present would listen with the greatest interest.

The following lecture was then delivered:—

"Unsolved Problems in the Design and Propulsion of Ships."

By Francis Elgar, LL.D., F.R.S., M. Inst. C.E.

The "James Forrest" lectures were commenced in the year 1892 with a most appropriate and well-remembered one by the late Sir William Anderson upon "The Interdependence of Abstract Science and Engineering." That struck the note which has been most prominent in the subsequent lectures, whatever were the particular branches of science or engineering treated in them; and no better note could have been struck, because it is the recognition of this interdependence, and of its great importance to practical engineers, which underlies the work and prompts the activities of this Institution.

The principal divisions of this general theme were developed in fuller detail by successive lecturers down to the year 1902. A new series was entered upon in 1903, which was commenced by Mr. W. H. Maw, with a lecture upon "Unsolved Problems in Engineering." Mr. Maw stated that it was desired to draw attention to the directions in which the further aid of the physicist is more immediately required by the engineer; and that in future lectures separate branches of inquiry, such as he sketched out, would be dealt with in greater detail. That course has since been followed, and I have been honoured by the invitation to address you this evening upon the branch which relates to the design of ships. I understand, however, that I am not desired to

wander in my remarks outside the spacious bounds of the mercantile marine; while our good friend Mr. Forrest, who proposed the subject of this lecture, helped me over the difficulty of trying to bring it within reasonable compass by suggesting the point of view of "the direction future progress may be expected to follow in the production of ever finer and faster liners than those which now traverse the ocean for trading and commercial purposes."

There are but few problems in the design of ships, as in most other branches of engineering, that can be exactly or completely solved in the full scientific meaning of the word, and those are of a secondary character. The primary or fundamental problems of safety, strength, speed, and steadiness at sea are far too complicated to be brought under anything like general mathematical treatment. The results obtained by the most advanced calculations cannot be applied directly to the real conditions of a ship at sea. After all is said and done, they merely relate to hypothetical cases which are simple in character, and are amenable to mathematical treatment. Some of these calculations are very elaborate, and their elaboration may sometimes tend to magnify their importance. The real problem is often very imperfectly dealt with after they are made; and it can only be solved approximately for working purposes by accepting the results of calculation for what they may be really worth, judging of the allowances required for their incompleteness, and using them in a scientific way and a scientific spirit to arrive at safe conclusions. We are obliged to come to a conclusion somehow, because we have to build ships as well as we can, whether we can solve exactly all the problems that arise in their design or not; and we have to take the responsibility of guaranteeing results, however difficult to obtain, or of declining to do so, within the time allotted for the preparation of designs and tenders, which is often very short. This is of the nature of engineering work of all kinds. To quote from our President's excellent inaugural address, "engineering problems differ from ordinary academically 'scientific' problems, partly in that they are much more complex, and consequently more difficult of anything like exact solution, and still more because—exact or inexact—some solution to them has always got to be found."

The nature of some of the principal problems that arise in the design of ships, and the extent to which their solutions are scientific, empirical, or merely tentative, will be indicated in some degree as I go on. I pass over what I venture to call the secondary problems of mensuration and hydrostatics—which relate to bodies floating in equilibrium in still water, and constitute the bulk of the ship-designer's purely scientific stock-in-trade—and will endeavour to

direct attention to some of the fundamental problems of a ship's behaviour at sea. I do not underrate, however, the great importance of those passed over, for it is the results of mathematical and physical research into the still-water properties and conditions of floating bodies which enable us, with the aid of observation and experience, to judge the probable qualities and behaviour of ships at sea. They also furnish the best data for comparisons between ships of varying dimensions and forms.

The class of problems that demand attention first are those which bear the most directly upon safety at sea. These are very general and comprehensive in character, and are impossible of anything like complete solution from the purely scientific side; but they are of vital importance, and solutions of them, which will be upon the right side, have got to be found somehow for every ship that is built.

Depth of Loading.

The first in natural order of the problems that relate to safety is the maximum depth of safe loading, or the minimum sea-going freeboard, for a ship of given size and type. Nothing ever caused more trouble in the shipping world than the arriving at an empirical solution of this vital problem some 20 years ago, and obtaining general acceptance for it. In the old days of sailing ships, and the early days of steamers, a standard number of inches per foot depth of hold was the ordinary simple rule for fixing freeboards; and that gave, on the whole, fairly uniform and satisfactory working results down to a certain time. But after the old rule of tonnage measurement, which merely took account of length and breadth of ship, was finally superseded by the present system of making internal capacity the measure of tonnage, types of cargo-steamers grew up which varied materially in proportions and form according to the trade in which they were employed, or the ideas of their designer. Diversities of type were promoted by the ever-increasing commercial competition among ship-owners, so that, as time went on, the question of the maximum depth of safe loading became more and more one which depended upon special features and characteristics of particular ships, or types of ships.

The losses of cargo-steamers, and of lives at sea, became so serious 25 to 30 years ago that many attempts were made to get a law passed for limiting depth of loading. The great difficulty and complexity of the problem resisted for a long while all efforts to deal satisfactorily with it. It was considered by many authorities,

upon all sides, to be impossible of solution. And yet it was obvious that individual shipowners, or shipping companies, were obliged to regulate the loading of their own ships in some way, and upon some system, or make it the duty of others to do so. It followed, therefore, that if the knowledge and experience of those separately responsible for the loading of the various sizes and types of vessels could be brought together and analysed, it ought to be possible to frame rules and tables of freeboard which would embody the results of safe loading, and prevent steamers from being sent to sea in a dangerously overladen condition.

The present Board of Trade freeboard rules and tables, which limit, by an Act of Parliament passed in 1890, the depth of loading of British ships, were arrived at in this manner. The first official tables were prepared in 1885 by a Committee appointed by Mr. Chamberlain, when he was President of the Board of Trade, and presided over by the late Sir E. J. Reed, a member of Council of this Institution. They were based mainly upon data which Mr. Martell, the Chief Surveyor of Lloyd's Register Society, collected, analysed, and put into the form of tables. The Board of Trade Committee obtained much additional data, and brought Lloyd's tables up to date, both in respect of figures for freeboards and of allowances for variations from standard types and dimensions. The Committee's tables were officially adopted; and freeboards regulated in accordance with them were accepted by the Board of Trade. In the year 1890, they were made compulsory upon all British ships.

The freeboard rules and tables of 1885 applied only, of course, to existing sizes and types of ships. Rapid developments took place in dimensions, and in distinctive types of cargo-boats, so that extensions and modifications of the original tables became necessary at times, in order to provide for altered conditions. The statistics of loading also became much more complete as experience was gained, and as it showed where corrections could be made with advantage. The principal alterations and additions were made in 1898, as the result of recommendations to the Board of Trade by a second Departmental Committee: and further corrections have been applied, from time to time, at conferences between the Board of Trade and representatives of the classification societies, to whom the duty of assigning freeboards is entrusted.

The real problem in fixing freeboards is that of the height of side above water which is requisite in order to prevent seas breaking upon the deck so heavily as to overcome the protection of the deck-openings and to find their way below, and also to enable

the officers and crew to work the ship in safety from the deck in the worst weather. One of the most important factors is strength of deck, especially the efficient protection of deck-openings by high casings and strong well-covered hatchways. Many of the worst losses have occurred through imperfect protection of deck-openings. Hatchway coverings, or light houses on deck which enclose openings, have been carried away, large bodies of water have passed below in increasing quantities as seas swept over the ship, and she has ultimately foundered. There have been cases where the tops of the openings into the stokeholds were only about a foot above the freeboard deck, and heavy seas got down through them, put out the fires, and gradually sank the ship. It is now usual to protect the engine- and boiler-hatches by casings which are carried several feet higher than the weather-deck to which the freeboard is measured; and the standard freeboards are only assigned to ships in which the engine- and boiler-casings above the upper deck are of sufficient height and strength, and the weather-deck hatchways are properly and substantially framed, and securely fitted with strong covers.

The close attention paid during recent years to the protection of openings in the weather-deck, in association with the strict limitation of loading now enforced by the Board of Trade freeboard tables, has resulted in an extraordinary diminution of losses at sea. The effect upon safety of the present regulations, and of the improvement all round in the size, strength, and equipment of ships is shown by the yearly statistics of losses; and it is well that some of the figures should be known. In the three calendar years 1881–83 there were 1,982 of the British ships registered in the United Kingdom, exclusive of fishing-vessels, lost at sea from all causes—foundering, stranding, collision, and missing—and 5,599 lives of crew in them, besides 332 passengers. For the three years ending 30th June, 1906, the corresponding figures were 654 ships, 1,394 lives of crew, and 133 passengers—and over 100 of the passengers were lost in the channel steamer "Hilda," on her voyage to St. Malo in November, 1905. The number of lives of crew lost at sea has thus been reduced to one-fourth of what it was 25 years ago; while not more than thirty passengers, besides the unfortunate victims of the "Hilda" disaster, lost their lives in all the vessels, large and small, that were lost at sea during the three years ending 30th June, 1906. If we consider merely the cases of foundered and missing ships, and omit those lost by stranding and collision, which do not directly affect the ship-designer, and also omit all small craft below 300 tons

gross register, as well as fishing-vessels and yachts, the results are as follows :—In the three calendar years 1881–83, 264 ships and 3,006 lives of crew. In the three years ending 30th June, 1906, 55 ships and 670 lives of crew. The figures here given are for steamers and sailing ships. If those for sailing ships could be taken out, the results would show still better for steamers, as the percentage of losses to those carried in sailing ships is about the same at both periods. The great reduction has been in steamers. It will thus be seen that however empirical or tentative the procedure in this matter may necessarily have been, the result is a very large and gratifying saving of life and property at sea.

Watertight Compartments.

An important element of safety at sea is the division of the hull into separate watertight compartments. A collision with another ship may occur, and it is necessary to provide, in such case, against rapid foundering. Much attention has been given to this point during recent years, especially in large passenger-liners. The number and positions of the watertight bulkheads in these are often regulated so as to carry out the recommendations of the Board of Trade Bulkheads Committee, presided over by the late Sir E. J. Harland in 1891. The problem was how to subdivide large ships so that they may float in moderate weather with any two compartments in free connection with the sea. The solution adopted by the Bulkheads Committee was to so place the bulkheads in large liners, and in all cross-channel passenger-steamers, that when any two adjacent compartments are laid open to the sea the uppermost watertight deck to which the bulkheads extend, called the bulkhead deck, would not be brought nearer the water surface amidships than 3 per cent. of the depth of the ship below that deck, and at the ends not nearer than 1½ per cent. The arrangement of bulkheads necessary to satisfy this condition can be determined by calculation for any particular ship, with proper allowances for the displacement of the contents of engine- and boiler-rooms, holds, etc., or it can be fixed sufficiently near for practical purposes, in many cases, by reference to curves and tables appended to the Committee's report which give the spacing of bulkheads for standard cargoes. The case of any two compartments freely open to the sea, in which the ship's pumping-power would be of no avail, is so extreme that the Bulkheads Committee's solution of this problem evidently provides a margin of safety in the event of accident.

Compliance with the Bulkheads Committee's rules is optional on the part of shipowners; and, although they may be sometimes used as a guide in fixing the positions of bulkheads, full compliance with their requirements is by no means general, even in the highest class of steamers.

Stability.

The next point of vital importance to safety at sea is stability. The stability of a ship when floating in equilibrium in still water is readily calculated, and is represented graphically by curves which show at any angle of inclination what the righting moment is which operates to move her back towards the upright position, supposing her to have been forcibly inclined away from it. These are called curves of stability: and they are usually made for several critical conditions, such as the light condition, the condition for dry-docking, the fully-laden condition, assuming the bunkers full of coal and all the cargo-spaces filled with homogeneous cargo of a density that immerses the ship to her load-water line; and also the last-named condition, after all coal, water, and consumable stores are exhausted; together with any others that require special attention. The general features of a ship's stability are thus shown very completely for the assumed still-water conditions; but her designer is obliged to trust to his judgment for making it satisfactory for sea-going purposes, although he often knows little of what it may become under working conditions upon a voyage. I made two voyages in a large ocean liner not long ago, whose metacentric height is about 7 inches when light, and 18 inches when filled with passengers, stores, fresh water, coal, and a homogeneous cargo of such density as completely fills all the cargo-spaces and immerses her to her load draught. I estimated the weights of cargo, coal, water, stores and passengers on board at the time of sailing, and the heights of their centres of gravity, and corrected the figures from day to day during the voyage as coal, water, and stores were consumed. The results were that at sailing upon the first voyage the metacentric height was 2 feet 2 inches, at the middle of the voyage it was 21 inches, and at the end 20 inches. Upon the second voyage the metacentric heights were 2 feet 10 inches at starting, 16 inches in the middle of the voyage, and 20 inches at the end. The irregularities in the metacentric height from day to day were largely due to the manner in which the water-ballast was used. This was a case of an ocean liner, in which the weights carried were about one-half the fixed weight of the hull and machinery. In a large cargo-steamer, where the weights carried may amount to twice the weight of the hull and

machinery, it will be seen how much the stability on service depends upon those who regulate the loading, and how little upon the designer.

The ship-designer requires to decide, of course, what metacentric height to give a ship in the circumstances to which his calculations apply; but it is only by comparison with other ships of similar types, that have been found satisfactory after passing into the hands of their owners, that he can properly fix the exact figure. In passenger-liners the righting moments at large angles of inclination are usually great, because of the height of side above water and the position of the centre of gravity. Even if the metacentric height were allowed to become nil, they would only incline to one side or the other without serious risk of capsizing, so long as all openings in the sides are properly closed. The case is different with many cargo-steamers, and was very different about 25 years ago with a class of vessels then largely engaged in carrying grain and coal cargoes. These were so constructed as to enable them to load with cargo to the under side of the upper deck; but they had insufficient beam to give a safe margin of stability when so laden. They were fairly safe if only light cargoes were placed in the 'tween decks, or when these were but partially filled; but if they were filled, as sometimes happened, to the under side of the upper deck with homogeneous grain-cargoes, the metacentric height came down to 6 inches, or less: and owing to this and their low sides, combined often with shifting of cargo in bad weather, the number lost by taking a heavy list and foundering at sea was considerable. This class of ships figured largely in the tragic list of losses of the early eighties.

The question of stability was raised before the Loadline Committee of 1885 in connection with the regulation of freeboards, and has often been revived since. It has been felt, however, that stability is so intimately related to stowage, and is so much in the hands of those who regulate the stowage, that it would not be satisfactory to treat it as a mere factor of depth of loading. Nothing can make a ship safe if her stability is not secured by proper stowage; but when vessels obviously admit of being loaded with homogeneous cargoes so as to reduce the stability dangerously at sea, the official bodies who assign load-lines should look for proof that the danger is understood, and that proper measures will be taken in regulating the stowage to guard against it. I believe this is the course taken by the Board of Trade, and the authorities who assign freeboards, when cases of such a nature come before them.

STRUCTURAL STRENGTH.

One of the most important elements of safety at sea is structural strength; and there is no more intricate, or difficult, problem which we have to consider. Mercantile steamers have been made what they are, in design and strength of structure, chiefly by observation and experience of the effects of straining action at sea. The usual calculations of strength of structures do not carry us very far by themselves in shipbuilding; and although much attention has been given to these by ship-designers, they cannot be greatly relied upon in practice. As a matter of fact, the arrangement of material shown upon the transverse section of a ship, and the sizes of the various parts, are practically what they have been made from time to time by Lloyd's Register Society. Classification at Lloyd's is so important in the mercantile marine, for the purpose of insurance, that the design of a ship's structure is usually little, if any, more than compliance with Lloyd's rules and tables. I use Lloyd's in this connection as a generic term, which includes the other shipping registration and classification societies, as it is the one of outstanding and dominant influence. It is seldom that structural design amounts to more than satisfying a Register Society that its requirements for classification, as laid down in rules and tables, have been complied with. These rules have been modified as ships increased in size and varied in type; and when exceptional ships not directly provided for in them have to be classed, the structural design is specially dealt with. But the governing principle throughout is experience of the behaviour of ships at sea. Lloyd's Register Society has representatives in all the principal ports of the world, who deal with and report all defects in the ships that come before them. There is no reason to fear that any weak point will escape the attention of Lloyd's surveyors. It is chiefly in this way that Lloyd's rules have been built up, from the earliest days of iron ships. Lloyd's Register Society has also done, and is still doing, much in the way of scientific research. It possesses a highly-trained technical staff, which has conducted and published some of the most valuable investigations yet made of the structural strength of ships. But the great problem of how to obtain the requisite strength of structure with the minimum weight of material is extremely difficult of approach from the scientific side. The usual calculations of structural strength are based upon still-water conditions. The most important are those which relate to

longitudinal strength, because the greatest stresses that come upon a ship are in the longitudinal direction. In these calculations the structural portion of the hull is regarded as a steel girder supported over the whole of its length by the upward pressure of the water. We take a ship floating in equilibrium in still water, and calculate the longitudinal distribution of the support from bow to stern that is given by the upward pressure of the water—which agrees with the curve of sectional areas of the underwater portion of the hull—and also calculate the weight of the ship and her contents per unit of length, and represent that by a curve, or rather by an irregular line, which gives the longitudinal distribution of the weight of the girder and its load. With these two factors—the longitudinal distribution of load and the longitudinal distribution of support—the bending-moments and maximum stresses upon the structure can be estimated according to the theory of the strength of girders.

In order to approximate somewhat to the worst conditions at sea the maximum stresses at the top and bottom of the structure are calculated for two hypothetical cases of support upon a wave-surface. The surface usually taken is that of a trochoidal wave of the same length as the ship, whose height is one-twentieth of its length. The vessel is first assumed to be floating in equilibrium upon one of these wave-crests with her bow and stern in the adjacent hollows, and next to be supported at the ends upon two wave-crests with her midship part in the hollow between them. The whole system of wave-water is supposed, for the purposes of the calculations, to be fixed for the moment, and the ship to be floating upon it in statical equilibrium.

It is not known how nearly the results given by calculations, which rest upon assumptions differing so widely from the real circumstances, correspond with the maximum stresses really brought to bear at sea, but it is certain they are often much in excess of the truth. In the new Cunarders, "Lusitania" and "Mauretania," the limiting stress accepted by Lloyd's, as determined by calculation, was 10 tons per square inch—for mild steel whose ultimate tensile strength is 28 to 32 tons per square inch. This gives an apparent factor of safety of only 3.

Many vessels have been running for years in which the figures obtained by similar calculations for the maximum stresses would amount to 10 tons per square inch. This must be largely in excess of the truth, and it is impossible to say exactly by how much. One important cause of the excess, worked out in detail by Mr. W. E. Smith, of the Admiralty, many years ago, is, that the buoyancy of wave-water is not the same at all parts of a wave, being less at the

crest and more at the hollow than that due to the weight of the volume of water displaced. This property of wave-water can be allowed for approximately in the calculations, and the necessary corrections made. These effect a substantial reduction of the calculated stresses in both the extreme positions upon a wave-surface; but they are not applied in practice, as the results are only used for purposes of comparison, and such a correction would not materially affect mere comparisons. The quantitative values of the calculated stresses are thus extremely doubtful. Even in comparing them with figures obtained in a similar way for other ships it is necessary to be careful not to press the comparison too far. Attempts have been made to measure the actual stresses at sea upon portions of a ship's structure by means of strain-indicators. Extensive experiments were carried out in H.M.S. "Wolf" a few years ago by an Admiralty Committee with Mr. Stromeyer's indicators, which gave some interesting results; but very little real progress has yet been made towards a quantitative solution of the strength problem.

The strength of ships, and the weight of the structural materials employed to give that strength, having become what they are by a long process of adding to, and building up, the structure in detail, and reinforcing weak points wherever they have been found, and by checking the general effect of such procedure in the imperfect manner that is alone possible by calculations of the kind referred to; it becomes a question how far the results arrived at may be considered satisfactory or final. All who have studied the great problems of ship-design, and know how they were solved in the design of the "Great Eastern" by Mr. Brunel, must agree with the opinion expressed by Sir William White in his Presidential Address of nearly 4 years ago, that "in structure she was not merely a marvel considering the date of her construction, but is still a most fruitful and suggestive field of study." The "Great Eastern" proved by her Atlantic voyages to New York and Quebec, and her subsequent experience in the trying work of cable-laying in the Atlantic, that she was quite strong enough for anything required of such a ship; and if we compare her structure with that of the standard ship of her dimensions and type to-day, which embodies the results of 50 years' more experience than her designer had at command, it appears very remarkable. Sir William White came to the conclusion, which I believe is right, that after making full allowance for features of modern designs that involve additional weight, which the "Great Eastern" did not possess, her structure was lighter than that of the corresponding ship of to-day—although the latter is built of steel 50 per cent. stronger than the

iron plates of the "Great Eastern," and the riveting of the edges and butts of plating is much more extensive and efficient, and is performed by hydraulic power in those parts where strength is most important.

The leading features of the "Great Eastern's" design included a very strong cellular double bottom, continued up the sides to a height of several feet above the water-line, a double-plated upper deck of cellular construction, and two longitudinal bulkheads for about half the ship's length amidships, which connected the cellular upper deck with the double bottom. There was no plating upon any deck except the upper deck. The structure of the corresponding steamer of to-day would consist of a very strong and deep double bottom of cellular construction, which is quite flat and stops at the turn of bilge; side plating above this which is doubled at the upper part, and is supported by very strong transverse frames about 30 inches apart; and four strongly plated decks, the upper structural deck and three below it, of approximately equal strength—with a fifth plated deck above these, in many cases, for about half the ship's length amidships—at about 8 feet apart.

The difference in principle between these two designs is so great, and the comparison of the respective weights of material so much in favour of the "Great Eastern," that there certainly seems to be a case for careful investigation, and for considering seriously whether a radical change in the structural design of large ocean liners might not be made with advantage. Novel structural arrangements are being constantly introduced into the design of cargo-steamers in order to give large open holds and facilitate stowage. Some are now being built of large size and depth, with only a single strongly plated deck at the top; and there seems no reason why this principle should not be applied, to a considerable extent, to large passenger-vessels. Any saving of weight thus effected would not only save cost, but would better enable the difficulties of draught of water in harbours and docks, for the largest ships, to be overcome.

Speed.

The problem of speed has always been a very vexed and difficult one, and there is none which has caused more trouble, or has given rise to more fallacies in theory and errors in solution. I cannot even direct attention now to the numerous theories, and the various approximate formulas, that have been invented and employed from time to time, for explaining and solving the speed problem. These formulas are generally so restricted in their range of application,

and require so much knowledge of their limitations, and of the conditions under which they can alone be relied upon for results that are anywhere near the truth, as to prove dangerous traps to the unwary and ill-informed. The man who can use them intelligently and safely, and with full knowledge of their limitations, and their tendencies to error, is able to deal with the speed problem fairly, completely and effectively—and I shall confine my remarks to the way of doing that.

The practical solution of the speed problem was effected by the late Mr. William Froude when he discovered the law of similitude or comparison which enables the resistance of a model, as ascertained by experiment, to be used for calculating the resistance of another model upon a different scale, or that of a full-sized ship, of similar form. He found that, over and beyond surface friction and other minor causes of resistance that are about proportional to it in well-formed ships, and may for purposes of calculation be included in it, the only element of resistance is that due to the formation of waves created by the passage of a ship through the water. When the forms of model and ship which originate the waves are similar, and travel at speeds proportional to the square roots of their respective dimensions, the wave-configurations thus created will be similar in every respect, and be proportioned to each other upon the same relative scale as that of ship and model. Hence it may be deduced from theory that the resistance caused to these forms by the development of the waves would be proportional to the cubes of the dimensions of the forms.

The law of frictional resistance was investigated by experiment, and was found to vary at a somewhat lower rate than the square of the speed, and to be affected by the absolute length of the surface immersed; and the figures for various natures and lengths of surface were determined experimentally by Mr. Froude. His analysis of the separate elements of resistance, showing that the two principal elements, friction and wave-making, varied independently of each other, and the latter in a very irregular manner, explained why simple approximate formulas are so untrustworthy.

What is wanted for the practical purposes of a designer is the means of ascertaining the resistance of a ship of given dimensions and form at any desired speed; and also of readily determining the precise form, or degree of fineness, of underwater body that would enable the maximum of carrying power to be obtained, in a given case, at a moderate rate of fuel-consumption. It is one thing to know exactly what power is required to give a ship of given dimensions and form the speed asked for or promised, and quite another to determine

what are the dimensions, form, and degree of fullness that will give the maximum passenger and freight-carrying capacity, with moderate engine-power and expenditure of fuel. Ships are sometimes built unnecessarily fine for the speeds at which they have to run, and might be made fuller, so as to carry an increased weight of cargo, without materially affecting their speed or coal-consumption. It is the determination of the precise fullness of form that is most advantageous, upon which the success of a design often depends.

In order to exhaust the problem of the best form of ship to meet the requirements of any particular trade or service, considerable investigation is required. This can only be made satisfactorily by testing the resistances of models in an experimental tank upon the late Mr. Froude's system.

Dimensions and draught of water are usually fixed beforehand by commercial considerations, and by harbour and dock facilities, at any rate within somewhat narrow limits; and the designer requires to test models of varying degrees of fineness in order to determine the point beyond which the further increase of engine-power and consumption necessitated by fuller lines would be unprofitable. This can be done best in an experimental tank. That method is unfortunately impracticable for ship-designers in this country, because there is no experimental tank available here for general use. The very few that exist belong either to the Admiralty or to private shipbuilders, and are confined exclusively to the work of their owners. I have had experiments made occasionally for my own purposes, but had to go abroad for them. The experiments required by Mr. Yarrow for his valuable investigations into the effect of shallow water upon speed were made in the North-German-Lloyd tank at Bremerhaven—where other experiments also have been made for him. A British shipbuilder can only get such experiments made by setting up an independent establishment for himself, or going abroad. Now an experimental tank, with its equipment and a competent staff for working it, is very costly to create and maintain. And over and above the cost of construction, and of running it, there is the all-important question of the quality of the results it will produce. It is not enough to procure a tank and equip it with all the requisite apparatus and appliances, and to attach to it a staff of scientific men to run models and take records of their speed and resistance. The work is of so delicate and intricate a nature that the personal qualities of the experimenters count for very much in it. The results obtained by the late Mr. W. Froude, and the present Mr. R. E. Froude, owe

much of their value to the exceptional qualifications of those eminent men for scientific research, especially upon the experimental side. It is the men, and not the tools, who constitute the most important factor in work such as this; and the right men for it are very difficult to get and to keep.

An attempt has been made recently to provide an experimental tank at the National Physical Laboratory, to be worked by members of the staff there, at which ship models might be tested for resistance; but up to now this has been without result. There is another way of dealing with the matter, however, and a readier one for the ordinary purposes of the ship-designer, initiated by Mr. R. E. Froude, that promises to overcome the difficulty in a satisfactory manner. Mr. Froude read a Paper at the Institution of Naval Architects, 3 years ago, upon "Some Results of Model Experiments," in which he gave the results of a series of general experiments on systematic variations in form of hull, the variations consisting of six different sets of typical lines, varied in proportion by independent variations of length, beam, and draught. The resistance-data given by these experiments are published in the Paper in such a form that the resistance of a ship of any dimensions, whose lines are similar to the typical ones, which are also given, can be readily taken out. The types dealt with have block-coefficients, or ratios of displaced volume to product of length, breadth, and draught, varying from 0·4865 in the finest to 0·541 in the fullest. Now this covers a very important class of mercantile steamers—that of fast Channel boats—and the designer of such a boat could have nothing better for his speed-calculations than the data in this Paper. He has only to refer to Mr. Froude's tables and diagrams in order to determine at once the proportions and form that will best suit the circumstances, and to construct the lines of his boat.

There could be no better solution of the speed problem, for practical purposes, than a continuation of the work that Mr. Froude has thus commenced. This would be the greatest boon to ship-designers. The method has been employed with most successful results in the practical design of ships of the class just mentioned. I know of three vessels which have been made to approximate closely to Mr. Froude's forms, and whose estimates of speed have been based upon his data. The turbine-steamer "Dieppe," which runs between Newhaven and Dieppe, is intermediate in form between Mr. Froude's No. 5 and No. 6 types. Her block-coefficient of fineness is 0·538, with a water-line length of 280 feet and a speed of over 21 knots. She had to be increased in beam, and made fuller in form than the previous vessels of the line, in order to carry additional weight upon

dimensions and draught of water that were strictly limited, without reduction of speed; and the best data available for determining the form that would fulfil these exacting conditions were Mr. Froude's. The result was a conspicuous success, as the "Dieppe" proved to be the fastest boat of the line. The same procedure was equally successful and satisfactory in the new turbine-steamer "Viper," of the Burns line between Ardrossan and Belfast, another 21-knot boat whose lines are those of Mr. Froude's No. 4 type; and in the twin-screw steamer "Hazel," fitted with ordinary reciprocating engines, just built for the Laird line between the Clyde and North of Ireland, whose length is 260 feet and service speed 18 knots, and whose lines were also based upon those of Mr. Froude's No. 4 type.

These results of the practical employment of Mr. Froude's methods and data are sufficient proof, if such were needed, of their value; and it may be said that, for ships represented by his types, the ship-designer is practically independent of further tank-experiments. The power and speed data necessary are all recorded in Mr. Froude's curves and tables, ready for immediate use. If similar data could be obtained for other forms of ships, say for the fast-liner type, with block-coefficients varying between about 0·6 and 0·7, the designer of that class of vessels would indeed have cause to be grateful. The best practical solution of this long-vexed problem of the relation of power to speed appears to be an extension of Mr. Froude's system to vessels of the fast-liner type, and to others with which the ship-designer often has to deal, leaving those of abnormal proportions or form, and freaks, and also the work of general research, to a public experimental tank—if ever we find enough enterprise among those interested to get one set up in this country.

Screw-Propellers.

The resistance of a ship may be estimated to a close degree of accuracy in the manner I have mentioned, but the determination of the engine-power required to overcome that resistance involves, among other things, the important consideration of screw-propeller efficiency. The problem of the most efficient design of propeller for any given size and form of ship, and rate of turning of the shaft, is as yet far from practical solution.

Several attempts have been made to construct a theory for the action of the screw-propeller. This involves, however, certain ideal assumptions for simplifying the problem, which would otherwise be too complex for treatment. It does not appear likely that any

purely mathematical theory will be found sufficiently reliable to enable the best dimensions of the screw to be determined for a given ship, and consequently we have to fall back upon the experimental method. This was developed by the late Mr. W. Froude, and has been continued by Mr. R. E. Froude in the Haslar tank. Model-experiments have been carried out there with a large number of propellers of varying pitch, diameter, and developed area; but the model screws have been very small, as the size and speed at which they could be worked were limited by the stresses the experimental mechanism is capable of bearing. This difficulty has been greatest with screws for turbine-vessels, because the revolutions are higher for them than for reciprocating engines; increased speed of turning being necessary to secure good turbine-efficiency. Mr. D. W. Taylor has carried out a very elaborate and comprehensive series of experiments, with propellers of larger diameter, in the United States Navy tank at Washington. The diameter of these propellers was 16 inches.

In applying the model-screw results to full-sized ships, recourse must be had to a law of comparison, similar to that obtaining between the model of the hull and the full-sized ship, and it is very important that further investigation should be made in this direction. It might be done by carrying out experiments in a tank on a larger scale, and with stronger appliances than those now employed in our Admiralty tank. A still more effective method, which I hear is under consideration by Mr. Froude, would be to build an experimental launch, with propelling machinery of considerable power, for running in open water. The machinery could be arranged so that the thrust of the screws and the torque on the shaft would be automatically recorded, as in the case of tank experiments. With such an arrangement, screws up to 3 feet in diameter could be experimented with—a great advance on anything that could be hoped for in the tank—and the important problem of propeller-efficiency might be brought nearer to a practical solution.

Steam-Turbines.

We now come to the greatest problem of all with regard to the propulsion of ships, and that is the form which propelling machinery is likely to take in the immediate future. Already an important change is in progress from the ordinary reciprocating marine engine to the steam-turbine; and the question is not only how far that change will extend, but whether the whole of the cumbrous apparatus required for producing steam may not before very long be swept out

of mercantile steamers, and the power be obtained from some form of internal-combustion engine. It would be rash to attempt to prophesy what will happen, but a short reference to the present position of these questions may be expected.

The progress of the steam-turbine is remarkable. It has often been described by Mr. C. A. Parsons and others, and is well known. The reasons why its progress has not been greater, and why it is not already more generally employed in ships of all classes, are perhaps not so well known, and it may be useful to consider them. The Parsons steam-turbine has practically superseded the reciprocating engine in the battleships, cruisers, and smaller very fast craft of our Navy, and it has had equal success in the very important class of Channel-steamers, and in other boats of similar type. Turbine-steamers now employed upon cross-Channel services are running at speeds that could not be reached with reciprocating engines. These vessels are limited in many cases to a very shallow draught of water, and consequently to a small diameter of propellers; they carry very little dead weight of coal and cargo; the weight of their machinery and boilers constitutes a large portion of their gross weight; and the percentage of the latter that is saved by the use of fast-running turbines is sufficient to give a substantial advantage in speed. The coal-consumption compares favourably with that of the best reciprocating engines of equal power that could be fitted in this type of ship; and still better, of course, with that of the paddle-engines, or screw-propeller engines of old type, which were in the boats they superseded.

When these facts are stated, as they often have been, surprise may be felt that similar advantages are not secured more extensively in other classes of vessels. Very few ocean steamers have been fitted with turbine-machinery, or are being so fitted; and although this may not be wondered at in the case of cargo-boats and other vessels of low, or even moderate, speeds, it may appear strange that liners of high speeds are still being fitted with reciprocating engines; and that the bold lead given by the Cunard Company with their two fastest new boats, and the "Carmania," should not be generally followed.

The chief reason for hesitation to put turbine-machinery into ocean liners is the doubt which exists as to coal-consumption. The amounts at stake are so large in these costly vessels, when experiments with novel propelling machinery are tried, that everybody prefers to see someone else make them. The Cunard Company are making the crucial experiment upon the largest scale that is now possible, and every one interested in progress must wish those

responsible for it all the success they hope for and deserve. But the result is still to some extent uncertain, and the immediate future of the turbine in fast liners depends greatly upon it.

In warships the consumption of coal with turbines has been brought down to about 1·7 lb. per equivalent indicated horse-power-hour of reciprocating engines, and the same in mercantile boats of cross-Channel type. That is as good as can be obtained with reciprocating engines in the same classes of vessels, as weight has to be kept down as much as possible in these by shortening the stroke, and using high mean pressures of steam in the cylinders, in order to get all the power that is practicable out of machinery of moderate size and weight. It pays better, in these cases, to stop somewhat short of the maximum efficiency that is attainable than to carry the additional weight of machinery which the increase would involve. In ocean liners the conditions are different, and economy of consumption is there the chief point aimed at. Their consumption with quadruple-expansion engines and a boiler-pressure of 210 lbs. to 220 lbs. per square inch has been brought down to about 1·3 lb. of coal per indicated horse-power-hour for all purposes. The substitution of turbines for reciprocating engines in ocean vessels depends chiefly upon whether the consumption with turbines can also be brought down to this low figure, and there is no satisfactory evidence that this is now practicable. It appears probable that the marine turbine may be ultimately so improved as to beat the best reciprocating engines in economy of consumption in ocean liners; but no proof is forthcoming that it can yet be relied upon to do it.

In ocean liners the turbine has to compete with the reciprocating engine at its best, and the development of high efficiency with the turbine is counteracted by loss of propeller-efficiency as speed of turning is increased. The problem is to secure a combination of turbine and propeller such as will give an efficient speed of the turbine without reducing unduly the diameter of the propeller; and experience with regard to this is much needed. The smaller propellers of turbine-engines doubtless gain in efficiency on service by being immersed more deeply, and thus being less affected by the rising and falling of the sea at the ship's stern. This is especially the case with some of the cross-Channel boats, in which the propellers have to be so large with reciprocating engines, relatively to the shallow draught of the vessel, even when run at the highest possible number of revolutions per minute, that they are sensibly affected by the least disturbance of water-level. The difference in propeller-efficiency soon becomes marked as the weather gets bad. In the Newhaven and Dieppe service, for instance, it is found that whereas

the turbine-boat "Brighton" only gains an average of 3 minutes throughout the year upon the time of the reciprocating-engine boat "Arundel" in crossing, she gains 15 minutes in bad weather. The difference in favour of the turbine on account of extra immersion of propellers might not prove so great as that in ocean liners, because in them the immersion of propeller is not relatively so unfavourable with reciprocating engines; but it would doubtless be of value. There appears to be some cause, however, which operates unfavourably in bad weather at sea, especially when running against a strong head wind, on turbine-vessels with comparatively small propellers. In such circumstances they sometimes fall off in speed more than reciprocating-engine boats with their larger propellers would do; and altogether, notwithstanding their greater depth of immersion, the efficiency of the propellers appears to diminish more rapidly as they are reduced in diameter, when driving the vessel against a head wind and sea. This may be chiefly a question of suitable design of propellers, which will be overcome after it has been ascertained more definitely how the efficiency obtained with them upon still-water trials is modified by sea-going conditions.

It may be interesting to give some particulars of two fast turbine-steamers that are being built by the Fairfield Company for the Egyptian Mail Steamship Company to run between Marseilles and Alexandria. These vessels will go upon their station at the beginning of next winter season. They are 525 feet in length, and their speed on service is to be 18½ knots. The turbines are to run at about 340 revolutions per minute, a rate which necessitates as small a diameter of propeller as prudence would allow. Everything has been done that appeared possible to favour the efficiency of the turbine and reduce the weight of machinery. The boiler-power is increased 6 per cent. above what would be allowed for reciprocating machinery of equal power, and the gross weight of engines, boilers, and auxiliaries works out about 400 tons lighter for the turbines. The space occupied by the boilers and machinery is practically the same; but the cost is greater. A larger consumption of coal with a corresponding increase of bunker-capacity has been allowed for, and it remains to be seen how the consumption will work out.

I am enabled, by the kindness of the General Manager of the London, Brighton and South Coast Railway, to give some further particulars of the speed and consumption of the Company's two boats, the "Arundel" and "Brighton," the one fitted with ordinary reciprocating engines, and the other with turbines. These vessels are approximately similar in dimensions, displacement, and form. The figures given are the averages of more than a year's running, during

which a total distance of about 20,000 miles was covered in each case. The average speed of the "Arundel" was 19·29 knots, with an average consumption of coal per trip, for all purposes, of 16·16 tons. The corresponding figures for the "Brighton" are an average speed of 19·59 knots, with 17·18 tons of coal. If the figures for consumption are corrected so as to give a comparison at equal speeds, it will be seen that there is little or nothing to choose between the two boats in economy of fuel.

The difficulties of stopping and manœuvring vessels propelled by turbines have been largely overcome by adding turbines of considerable power for going astern. In the "Dieppe" the astern turbines are two-thirds of the full power ahead, and she was stopped dead upon the official trials, when going at a speed of 12 knots, in $1\frac{1}{4}$ times her length; the time taken in bringing her to a standstill being 31 seconds.

The correct measurement of the power given out by turbine-machinery is a practical problem of the greatest importance to ship-designers. Messrs. Denny, of Dumbarton, have tried several ways of doing it, and have achieved considerable success with a telephonic recording apparatus for determining the twist of the shaft over a large part of its length, and thus obtaining a measure of the torque. The chief difficulty is in securing a sufficiently exact and definite record of the amount of twist. Others are experimenting in the same field, and there is good reason for hope that a satisfactory solution of this difficult and very delicate problem will soon be reached.

Internal-Combustion Engines.

The question of some form of internal-combustion marine engine suitable for large ocean vessels is still about where it was when Mr. Milton's Paper was read and discussed here last January; and I do not feel able now to add anything useful to that Paper and discussion. I will therefore merely enumerate the conditions, most of which were mentioned by Mr. Milton, that must be satisfied by a successful marine engine of any type whatever.

1. The engine must be reversible.
2. It must be capable of being stopped quickly, and of being started quickly either ahead or astern.
3. It must be capable of being promptly speeded to any desired number of revolutions between dead slow and full speed, and of being kept steadily at the required speed for any length of time. "Dead slow" ought not to be faster than

one-quarter of full speed, and should be less in very fast vessels.

4. It must be capable of running continuously for long distances, with but short intervals between the runs, without risk of stoppage or breakdown.
5. It must be capable of working well, not only in smooth water, but also in heavy weather, in a seaway, where the varying immersion of the propeller causes rapidly-changing conditions of resistance.
6. All working parts must be readily accessible for overhaul, and all wearing surfaces must be capable of being promptly and easily adjusted.
7. The engine must be economical in fuel, especially at its ordinary working-speed.
8. It must be compact, light in weight, and well balanced so as not to cause vibration.
9. It must not involve any risk of accumulation of gas in the ship such as could form an explosive mixture.
10. It is a *sine quâ non* that it must be capable of using a fuel of which the supply at a moderate price is practically unlimited, and which could be obtained readily in whatever part of the world a ship might happen to be.

We have since heard of gas- and oil-machinery for 16,000-HP. battleships, but this only exists at present in imagination. It is impossible to judge, by what has been successfully accomplished so far, what weight or space, or what consumption of fuel, would be required for the internal-combustion engines of great power that may perhaps be made ultimately to fulfil the onerous requirements of marine work. Engineers and metallurgists may succeed some day in overcoming the difficulties of producing large cylinders which will stand the high impulses, and the great and rapid variations of temperature, that occur with internal combustion; but till then no great step ahead can be taken. There are no two opinions, however, as to the advantages that would be gained by doing away with the present boilers and their appurtenances, and abolishing with them much of that very arduous and disagreeable class of labour known as marine stoking.

The subject of oil-fuel for marine boilers is interesting, but I have no time to say more than that great practical advance has been made with it during the last decade, and a consumption as low as 0·9 lb. per indicated horse-power-hour has been regularly realized in mercantile vessels which employ the system of spraying the liquid for combustion by means of hot air. American steam-

ships have used oil-fuel largely during the last 3 years, under a combined system of high- and low-pressure air respectively, for desiccating or pulverizing the oil before combustion and for assisting the combustion afterwards. This system has proved highly successful and economical. Vessels of 14,000 tons displacement belonging to the Shell Transport Company have made voyages regularly and successfully from Singapore to this country by the long route of the Cape of Good Hope, and still larger vessels have made equally successful voyages from New York to San Francisco via Cape Horn.

Comfort on Shipboard.

The securing of all the comfort that is possible for passengers on board ship is a modern idea. Formerly it was thought sufficient to take them safely, and without much regard even to time, to their destination, and very little attention was paid to mere comfort. Now it is the chief object of the best shipping-companies to leave and arrive in port on fixed days, and even at fixed hours, and to make the life of passengers on board ship as comfortable and luxurious as on shore. The great pioneer in this cause of convenience and comfort was the late Mr. Thomas Ismay, the head of the White Star line. He always held that the best ship for passengers was not necessarily the fastest; but that comfort and regular arrivals in port were even more important. The travelling public seems to be coming to Mr. Ismay's way of thinking. It does not appear to be so much the highest possible speed across the Atlantic that is now in demand by passengers, as convenience and comfort in travelling. What is looked for in passenger-liners to-day is indicated by the attractions held out in the shipping-advertisements. One line advertises, "the fastest, finest, and most comfortable of British steamers, including those wonderful hotels ——— and ———,"—the "wonderful hotels" being perhaps among the most popular of the ships, though they are far from being the fastest. A similar advertisement states that "the steadiness in all weathers of the ——— and ——— is remarkable. All passengers who suffer when at sea should travel by these boats. The experience will be a revelation to them." Among the other advantages and attractions advertised by steamship-companies are wireless telegraphy, submarine signalling, daily newspapers, gymnasia, passenger elevators, *à la carte* restaurants, grill-rooms, children's saloons and playrooms, and the landing and embarking of passengers directly on to, and from, the railway-train.

Much of the comfort and luxury now in such demand by

passengers is provided by those who manage the ships, and not by their designer. There is one very important element of comfort, however, which the designer can do much to supply, and to which increasing attention is given. I refer to steadiness at sea, and freedom from heavy rolling and pitching. The worst rolling is caused when a ship is among waves whose period in a direction transverse to her length approaches to synchronism with her own natural period of rolling. The steadiest ships are those whose natural periods of rolling are the longest, because these meet less frequently with waves of equal period to their own. In the largest ocean liners which have a reputation for steadiness, the period of a double roll is between 15 and 20 seconds, and the length of wave of approximately equal period to the lower figure would be about 1,100 feet. The designer who aims at producing a steady ship endeavours, therefore, to make her period of rolling as long as possible, and thus reduce the chance of meeting conditions of sea that would be likely to cause deep rolling. This can be done theoretically in two ways. First, by increasing the radius of gyration about the axis of rotation, and second, by reducing the metacentric height. Any attempt to deal with the former is practically out of the question, but the designer can make the latter what he chooses. He often makes it about 15 to 18 inches for the ideal conditions of loading assumed in the calculations; but he has usually no knowledge, as I have said, of how this may be sometimes altered by the actual loading. Whatever may be done by the designer to provide the metacentric height he may consider most conducive to steadiness, its proper regulation at sea, by suitable stowage of cargo and stores in the first instance, and by the judicious use of water-ballast afterwards, requires the careful and close attention of the ship's officers if unpleasant rolling is to be kept at a minimum. About 18 inches of metacentric height appears to give a satisfactory combination of resistance to inclination, in large ships, with a long rolling-period.

Bilge-Keels.

After reducing the tendency to roll as much as possible, by suitable regulation of the metacentric height, the next thing is to increase the resistance to whatever rolling there may be. This is done chiefly by means of bilge-keels, which oppose the whole of their surface to the motion of rolling, and when of sufficient depth are very effective in reducing its extent. In ships I have known, that have been fitted after they were built with bilge-

keels suitably formed and placed, the extreme angles of rolling have been reduced by one-half. The steadying effect of these keels is now well known and admitted in the mercantile marine.

Anti-Rolling Chambers.

Other devices have been considered, and some have been tried, for still further increasing the resistance to rolling. Sir Philip Watts described, in the Transactions of the Institution of Naval Architects for 1883 and 1885, the trials, in H.M. ships "Inflexible" and "Edinburgh," of free water in large chambers that extended right across the lower deck, the transverse motion of which, as the ship rolled, was regulated by the shape of the water-chamber and the depth of the water, so that it would operate as a drag or brake upon the rolling motion. The same device was tried in a small passenger-ship, the "Ohio," in 1887, and in the "City of New York" and "City of Paris" in 1889. In the two last-named ships the chamber was upon the orlop deck. These water-chambers appear to have given good results within certain limits of rolling, and when the motion of the water in them was well timed, but their action depended very much upon the way in which the water was regulated. Whether it was on account of this, or the space occupied, or because of other objections that exist to the free motion from side to side of large quantities of water in a ship, I do not exactly know; but whatever the reason may be, the idea was dropped.

Oscillating Weights.

A proposal has recently been made by Mr. Victor Cremieu of Paris to check rolling by means of a heavy pendulum of long period that would oscillate in a closed chamber filled with viscous liquid, and he has contributed a Paper upon the subject to the Académie des Sciences. His idea is to make the length of pendulum, and its weight, such as would give it an angular momentum up to possibly $\frac{1}{10}$ of that of the ship. The clearances between the pendulum and the sides of the chamber, and the degree of viscosity of the liquid—Mr. Cremieu suggests oil, or a mixture of water and glycerine—would be so arranged as to make the energy of the pendulum most effective in offering resistance to rolling. A simplification of the apparatus is suggested by substituting for the pendulum a weight that would move backwards and forwards upon a curved path, in a

transverse chamber or tube filled with the viscous liquid. In both cases the principle is that of opposing the rolling of the ship by the statical moment of the oscillating weight, and reducing the energy of motion by generating heat in the liquid through which the weight moves. Mr. Cremieu has shown by experiments with a small model that great extinctive effect upon rolling can be obtained by the last-named application of his method, with what appears to be a moderate amount of weight.

Sir John Thornycroft described in 1892 an automatic steadying apparatus which was fitted in his steam-yacht "Cecile" with some success. It consisted of a most ingenious controlling-gear which regulated the motion from side to side of a heavy weight in opposition to the rolling motion. It was very cleverly worked out, and destroyed much of the rolling in a vessel of great metacentric height and very short period. This idea also has not been followed up.

Gyroscopic Apparatus.

A device which appears promising for increasing the resistance to rolling has been ingeniously and effectively worked out by Dr. Otto Schlick, of Hamburg, a very eminent marine engineer. It depends upon gyroscopic action, and was explained by Dr. Schlick at the Institution of Naval Architects in 1904. The models he then used were of small inertia in proportion to the inertia of the gyroscopes mounted in them, so that the steadying effect was extreme; but Dr. Schlick expressed a confident opinion, based upon experimental investigation, that gyroscopic appliances having dimensions and weights suitable for ships would render it possible to control and limit their rolling motion when exposed to the action of ocean waves. He anticipated that the period of oscillation of ships might thus be increased considerably, while the angles of rolling might be largely reduced.

Dr. Schlick has since carried out an important series of experiments in the "See-bar," formerly a first-class torpedo-boat of the German Navy, with remarkable results. Sir William White described some of those experiments, which he witnessed at the mouth of the Elbe, at the Institution of Naval Architects last March; and he gave some interesting results of rolling under different conditions, which show that the extinctive effect of a comparatively small gyroscope is extraordinary. It would take a longer time than I have now at disposal to explain Dr. Schlick's apparatus, and, fortunately, that is not necessary, as Sir William White has a working model which he is to exhibit

at the Royal Society to-morrow evening, and he has very kindly lent it to me to show you here. The "See-bar" was in the Thames during the meetings of the Institution of Naval Architects, and we had an opportunity of seeing the gyroscopic apparatus in her. This contrivance appears to deserve serious consideration, and is already ripe for application to the smaller classes of steamers. I am informed that an apparatus is being manufactured for placing in the Hamburg-America Company's passenger-boat "Silvana," of about 1,000 tons, which runs between the Elbe and Heligoland; and that Dr. Schlick is designing a standard gyroscope which will be suitable for boats of about 1,200 tons to 2,000 tons displacement. This standard gyroscope will be electrically driven, except in cases where there is not a sufficient margin of electric power available in a ship, when it will be driven by a steam-turbine. An apparatus for vessels of the displacement named would be applicable to the class of Channel steamers, and we may perhaps see it tried before long in some of them.

Pitching.

What I have said with regard to making ships steady at sea has had reference only to rolling motion; but many consider it is not rolling that affects them so much as pitching, or as the skew motion near the ends of a ship that is neither rolling nor pitching, but an unpleasant combination of the two. There is also sometimes a vertical or heaving oscillation, when large waves are passing a ship broadside on, which may rise to an amplitude of several feet when the wave-period approximates to the period of the vessel's own dipping oscillations; but it is probably seldom that the motion from this cause is great. Pitching is often the chief cause of trouble and discomfort, and the motion due to it may be greater and more violent than any other, especially near the ends of the ship. The pitching period is sometimes as short as 4 seconds, so that there may be three or four pitches to one roll; and the vertical distance moved through near the ends in pitching is very much greater than at the ship's side during a roll.

After all that is possible has been done to make the forward transverse sections of a ship of such form as will resist pitching, and given good stowage, there still remains considerable tendency to pitch, in certain conditions of sea, which cannot be removed. The best way to avoid the ill effects of pitching is to get as near as possible to the axis of rotation, the position of which varies considerably, according to the nature and direction of the seas which

cause the pitching, but is usually not far from the centre of length. The modern large steamers which have their first-class passenger-accommodation upon three or four decks in the middle third of a ship's length are generally found to be the most easy and comfortable at sea. This is probably because the greatest vertical distance moved through in pitching, in that part of the ship, is only one-third of what it is at the ends. It is to this concentration of passenger-accommodation near the middle of a ship's length that we have to look chiefly, at present, for neutralizing the trying effects of pitching.

Vibration.

One of the chief causes of discomfort and distress to passengers on shipboard is vibration. This may be due to one, or more, of several causes, to which much attention has been given during recent years. The effect of reciprocating engines in causing vibration has been investigated by Dr. Schlick, Mr. Yarrow, Mr. Mallock, Professor Dalby, and others, who have demonstrated the manner in which such engines operate to cause vibration, and how to reduce this to a minimum by suitable design, and by balancing the principal working parts. There is little to choose, in a strongly-built ship, between modern well-balanced reciprocating engines, and steam-turbines, as regards smoothness of running, and absence of unpleasant vibration. Vibration is often due to the action of the propellers; and when these have to run at very high speeds, as with fast-running turbines, a certain amount of vibration is sometimes unavoidable. Apart from the essential conditions of trueness of propeller-blades, and exact balance of the propellers upon their shafts when turning, there is the action of the ends of the blades upon the water adjacent to the stern-plating, where they pass nearest to it in revolving, which is sometimes very violent, and causes a hammering effect that is occasionally most unpleasant. The vibration and tremor of this plating may be quite local, and may be checked by strong bracket-frames at the parts where it is greatest; or it may be communicated throughout the hull, and set up sympathetic vibrations in large flat areas of plating, such as decks, straight side-plating, bridges, etc. These difficulties can generally be overcome by careful attention to the surfaces that vibrate, and by stiffening or supporting them at a few critical points by struts or brackets. There appears to be no reason why ships should not now be kept free from all unpleasant vibration, both as regards the working of the main engines and the action of the propellers.

Fast-running auxiliary engines, fan-engines, and dynamo-engines often cause unpleasant vibration or tremor that is sharply felt, but this can be kept down by supporting them upon beds which are strong in themselves and are rigidly connected with the main structure.

General Remarks.

The tendency to increase the size of ships is strong and continuous. It has long been known that the power required to drive a ton of a ship's displacement at a given speed diminishes, and the working-expenses become less per ton all round, with increase of size. Mr. Brunel knew that when he designed the "Great Eastern." He stated the point, and also the limits of its application, in the following words:—"The experience of several years has proved, what was believed before by most unprejudiced persons, that size in a ship is a great element of speed, and of strength, and of safety, and of great relative economy, instead of a disadvantage, and that it is limited only by the extent of demand for freight, and by the circumstances of the ports to be frequented." The effect of size is felt most powerfully in bad weather, as the larger vessel is less affected by wind and sea, and does not lose so much time upon her voyages on that account. The ultimate limits of increase of size are fixed, as Mr. Brunel pointed out, by port-facilities and demand for freight. The subject of port-facilities will be brought forward to-morrow by Lord Pirrie in a Paper upon "Harbour and Dock Requirements as affected by the Development of Shipping," and will be discussed at the joint meeting of Sections II and V of the Engineering Conference, and therefore I need not dwell upon it now. I will merely offer a few remarks upon the other limiting condition, demand for freight.

There is a size and speed of ship that is most appropriate and profitable for each line of steamers, or each trade, and it varies greatly in different trades. The managers of the various lines know best what dimensions and speed are likely to be most profitable in their respective trades, and what are the maximum number of passengers, and the quantities and descriptions of cargo likely to be forthcoming. The most suitable sizes and speeds for mercantile steamers depend upon commercial and economic considerations of which the ship-designer usually has but an imperfect knowledge. His part consists chiefly in producing a design that will fulfil the necessary conditions of size, draught of water, speed, carrying-capacity, and accommodation for passengers, in the most efficient manner and at the minimum of cost. There is one

point, however, which is so important in considering further large increases of speed in ocean liners generally, that I would like to direct attention to it.

Speed is limited in passenger-liners, altogether independently of size, by economic considerations. High speed at sea is a costly luxury. It can be obtained by paying for it—up to 25 knots, as we see by the latest Cunard liners—but it has to be paid for by somebody. The extra cost cannot be got out of cargo-freight, for as speed is increased the proportion of space available for carrying cargo becomes reduced by the increase of boilers and machinery, and therefore less cargo is carried relatively to the size of the ship. This reaches an extreme limit in the fastest Atlantic liners, whose holds are as full as they can be stowed of engines, boilers, and coal for the voyage—their speeds being limited by the impossibility of getting more boilers in—and it is only a few odd spaces which cannot be utilized for other purposes that are available for carrying a little cargo. In these cases cargo is reduced almost to a negligible quantity.

It may be said generally, with regard to any line of steamers, that if speeds of more than 12 to 13 knots are desired the extra expenditure involved by such increase must be looked for outside the cargo. This element of earning-power does not bear an increase of rate of freight. There are only two sources from which payment of the extra cost of increased speed could come. One is from passengers and the other from a mail-subsidy. No mail-subsidy that could be proposed would pay more than a small portion of this extra cost: the greater part of it must come from passengers. What passengers have to pay for high speeds at sea may be seen by the rates charged in the fastest Atlantic steamers. Apart altogether from special cabins, or apartments *de luxe*, for which almost any prices are paid, the cost of a single first-class passage to New York varies from £22 10*s*. to £48 10*s*. for a run of 6 days in one of the fastest liners, according to the position of the cabin in the ship and the time of year—or from 1¾*d*. to nearly 4*d*. per mile travelled. These prices have risen rapidly during recent years as speed has increased; and passengers across the Atlantic who are willing to pay them appear to be forthcoming in ever-increasing numbers. If that were not the case such high speeds could never have been reached. No great improvement of speed is to be looked for upon the other main lines of ocean traffic, unless some revolutionary change is made in the mode of propulsion which will cut down the cost, or a sufficient number of passengers are found, as in the Atlantic trade, to pay the high rates it would necessitate.

I have not done anything this evening towards reducing the number of the many and difficult unsolved problems that trouble the mind, and tax the skill and judgment, of the ship-designer; but if I have succeeded in conveying some idea to you of their nature, and of the interdependence of science and engineering in all wise attempts at their solution, the main object I had in view will have been accomlpished.

Sir JOHN WOLFE BARRY, K.C.B., Past-President, said the very pleasant task was allotted to him of proposing a vote of thanks to the lecturer for his admirable address. Those who recollected their dear old friend, Forrest, and his firm but genial and sympathetic sway in the Institution found it difficult to realize how many years had elapsed since he gave up the helm, or that the present was the fifteenth "James Forrest" lecture. The members could look back upon this series of lectures with the greatest possible satisfaction. They had been, he thought, an unvarying success; they had introduced new investigations and new problems to the minds of all, and they had shown, in a very conspicuous way, the catholicity of The Institution. Every subject of science which could have been touched on in the past fifteen years had, he thought, been dealt with in the various lectures; and they had never listened to a more suggestive and interesting lecture than the one given that evening by Dr. Elgar. It was most satisfactory that naval architecture now formed a very prominent subject in the work of The Institution, and that the leaders of that profession, Dr. Elgar and Sir William White, were sitting on the Council at the same time. It must be highly interesting to the members of The Institution to observe the immense grasp of the subject of naval architecture possessed by their former Vice-President, Isambard Kingdom Brunel, and it was a remarkable thing that Dr. Elgar had been able to point out, how, 50 years ago, in a subject almost untouched in a scientific way, and dealing with ships built of iron, Brunel evolved first of all the "Great Western," a great step in advance of any ship at the time; then the "Great Britain," a still further step in advance; and last of all that wonderful ship the "Great Eastern," which was now recognized as a model to be studied by those who had to build the leviathans of modern commerce. It was remarkable also that, in a similar way, Mr. William Froude—who was a lieutenant of Brunel's and not in the first instance connected with naval architecture—like his master, devoted his acute intellect to the same subject; and

engineers were now indebted to Mr. Froude for having introduced a scientific and exact knowledge of the problems of ships, which the world previously did not possess in the slightest degree. As Dr. Elgar had stated, if designers wished to know how a ship would behave, they had to follow on the lines which Mr. William Froude had laid down, and which his son, Mr. R. E. Froude, was still following in that most interesting and important subject. It was a remarkable circumstance that those two gentlemen—Brunel and William Froude—began life as railway-engineers, and only devoted their intellects later to marine subjects, perhaps because they were a little tired of making railways and bridges and wanted new fields to conquer. The lecture which Dr. Elgar had delivered afforded great encouragement to the younger members of the profession, because, as the lecturer had said, he had not exactly solved many of the unsolved problems, but he had pointed out the direction in which younger men could go, and in which all of them had the opportunity of gaining the Field-Marshal's baton of success. It was a matter of congratulation to members of The Institution that their dear old friend James Forrest was in the enjoyment of good health, and took a most lively interest in all that went on at The Institution. He had the greatest pleasure in asking the members to accord a most hearty vote of thanks to Dr. Elgar for his admirable lecture.

Sir WILLIAM PREECE, K.C.B., Past-President, seconded the vote of thanks with the greatest pleasure. He was one of those who occasionally found it necessary to "go down to the sea in ships and do business in great waters," having crossed the Atlantic ten times. Thirty years ago the idea of the passenger was that the safety of the ship depended wholly on the captain; at the present day it was understood to depend very largely on the designing engineer. He had crossed to New York within the last 3 months on the "Caronia," a ship built with reciprocating engines; and came back on her sister ship, the "Carmania," fitted with turbines. The weather was as rough as it was when he first crossed in 1877; they encountered three severe gales, but it was not necessary to have the fiddles on the table on any occasion. He had examined the second- and third-class accommodation, and found that at the present day the third-class cabin accommodation and bills of fare were better than those of the first class of the "Abyssinia," 30 years ago. He wished Dr. Elgar's admirable lecture had been given before he (Sir William) made his recent trip, for he would then have watched with more interest the relative merits of the reciprocating engine and the turbine.

The resolution of thanks was carried by acclamation.

Dr. Elgar replied that he had felt it a great honour to be invited to give the "James Forrest" Lecture, and it had been a great pleasure to deliver it to so patient and attentive an audience. For any trouble he had taken in the matter he was more than repaid by the compliment The Institution had paid him.

ENGINEERING CONFERENCE, 1907.

THE Fourth Conference of The Institution was held on Wednesday, Thursday, and Friday the 19th, 20th, and 21st June. Accommodation was provided for six of the Sections in the Institution premises, and the remaining Section met in the Meeting Room of the Surveyors' Institution, which was very kindly placed at the disposal of the Council by that body. As on previous occasions, the Notes introducing subjects for discussion were considered in seven Sections, comprising the main branches of civil engineering practice; and visits to works were made on each of the three days.

The organization of the business of each Section was settled by groups of officers elected by a General Committee nominated by the Council for this purpose. The officers of each Section, who were responsible for the conduct of the business of that Section and for the choice of the subjects discussed in it, are given on p. 289.

The Conference was opened on the 19th of June by Sir Alexander Kennedy, LL.D., F.R.S., the President, who delivered a short address (see p. 290) to a combined meeting of all the Sections. At the subsequent meetings of the various Sections, forty-six Notes (see p. 294 *et seq.*) were read, eliciting from the members and others taking part in their consideration 425 speeches.

On this occasion an official verbatim report of the proceedings was prepared and published. This report has been issued in seven parts, each part containing the complete transactions of one of the seven Sections, and the charge for a copy for any one part being 2*s*. 6*d*.

Representatives of the Press were permitted to attend the meetings of the Conference; and accounts of the proceedings have appeared in many of the technical journals.

About 620 members received tickets for the fourteen visits to works (see list on p. 297). The total number of applications for tickets for the visits was 1,620; in respect of which the tickets actually issued, in accordance with the choice indicated and the conditions of the visits, were:—for the first day, 282; for the second day, 515; and for the third day, 372.

OFFICERS OF THE SECTIONS.

President—SIR ALEXANDER B. W. KENNEDY, LL.D., F.R.S.

General Secretary—J. H. T. TUDSBERY, D.Sc.

SECTION I.—RAILWAYS.

Chairman—WILLIAM ROBERT GALBRAITH

Vice-Chairmen: R. Elliott-Cooper; James C. Inglis; Alexander Ross; W. B. Worthington, B.Sc.

Hon. Secretaries: J. W. Jacomb-Hood; J. M. Moncrieff; B. Mott

SECTION II.—HARBOURS, DOCKS, AND CANALS.

Chairman—Sir WILLIAM MATTHEWS, K.C.M.G.

Vice-Chairmen: G. N. Abernethy; C. A. Brereton; W. H. Hunter; A. C. Hurtzig; A. G. Lyster; H. H. Wake

Hon. Secretaries: W. T. Douglass; J. A. Saner; M. F. Wilson

SECTION III.—MACHINERY.

Chairman—WILLIAM CAWTHORNE UNWIN, LL.D., F.R.S.

Vice-Chairmen: John A. F. Aspinall; W. H. Maw; Sir Andrew Noble, Bart., K.C.B., F.R.S.; The Hon. C. A. Parsons, C.B., D.Sc., LL.D., F.R.S.

Hon. Secretaries: H. F. Donaldson; E. B. Ellington; M. H. P. Riall Sankey

SECTION IV.—MINING AND METALLURGY.

Chairman—JOHN STRAIN

Vice-Chairmen: Sidney H. Farrar; R. A. Hadfield; J. B. Simpson; Sir Thomas Wrightson, Bart.

Hon. Secretaries: H. S. Childe; R. E. Commans; Sidney H. Farrar

SECTION V.—SHIPBUILDING.

Chairman—F. ELGAR, LL.D., F.R.S.

Vice-Chairmen: Sir J. Fortescue Flannery, Bart.; The Rt. Hon. Lord Pirrie, LL.D.; Sir Philip Watts, K.C.B., LL.D., F.R.S.; A. F. Yarrow

Hon. Secretaries: S. W. Barnaby; John List, R.N.R.; J. T. Milton

SECTION VI.—WATERWORKS, SEWERAGE AND GASWORKS.

Chairman—Sir GEORGE THOMAS LIVESEY

Vice-Chairmen: Sir Alexander Binnie; George Chatterton, M.A.; George F. Deacon, LL.D.; Harry E. Jones

Hon. Secretaries: E. P. Hill; J. D. Watson; H. Woodall

SECTION VII.—APPLICATIONS OF ELECTRICITY.

Chairman—R. E. B. CROMPTON, C.B.

Vice-Chairmen: J. A. Ewing, LL.D., F.R.S.; John Gavey, C.B.; W. M. Mordey; A. A. Campbell Swinton

Hon. Secretaries: H. R. J. Burstall; A. H. Preece; J. F. C. Snell

OPENING ADDRESS OF THE PRESIDENT,

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S.,
President Inst. C.E.

In opening the Proceedings of the Engineering Conference of The Institution of Civil Engineers, it is neither necessary nor desirable that I should detain you more than a very few minutes. The first of these Conferences was held in 1897—10 years ago—under the presidency of Sir John Wolfe Barry. It is sad to notice that among the Sectional Presidents in that year were no less than four of our distinguished members who have now passed away—Mr. Hayter, Sir Frederick Bramwell, Mr. Mansergh, and Sir Benjamin Baker. The second Conference was held under Sir William Preece in 1899, the third under Mr. J. Clarke Hawkshaw in 1903. The Conference which opens to-day is, therefore, the fourth of the series, and I hope that it may prove not the least interesting and useful of them.

During my year of presidency I have tried, in the too many speeches which I have had to make to our members, both here and throughout the country, to emphasize the essential catholicity of the aims of our Institution. There were days before most of us knew more about The Institution than that it existed, and that we hoped in the distant future to become members of it. It may have been that in those days, or perhaps somewhat later, one class or another of us constructive people thought a little too much of the importance of the sort of work which we particularly happened to be doing, and were disposed to be somewhat too exclusive in our classification of civil engineers. But if this were the case, it was certainly contrary both to the spirit and to the letter of our Charter, which appears to cover in definite words every branch of engineering which was in existence at the time when it was drafted—1828: roads, bridges, navigation and docks, harbours and lighthouses, marine engineering, machine construction, drainage. Railways, naturally, do not appear specifically, but, no doubt, were included prophetically under the heading of "Means of Traffic." Electricity was as yet unborn—perhaps we may consider that it comes under either "adaptation of machinery" or "means of production"! Anyhow, we are now very clear that all and every department of industrial activity which can possibly be covered by the name of "engineering" falls within the ken and the interest of our Institution, and that everybody working within such depart-

ments, and having attained a certain degree of knowledge, of responsibility, and of technical capacity, is a civil engineer, and ought, therefore, to be a corporate member of The Institution.

Our Conference has many objects; it brings together more members than can otherwise meet at any one time, it allows many members to take part in our proceedings who otherwise have little opportunity of doing so; it allows us to compare notes on a great variety of subjects in a useful, although informal, manner, and in a very short space of time; it gives opportunity to all of us for pleasant social intercourse with those who are our colleagues in everyday work. But probably the idea which I have mentioned of the catholicity of our Institution's aims and objects is really the fundamental idea which underlies the Conference. In spite of the very extended ground covered by the subjects of our sections, few of those who are asked to meet here and discuss these subjects are not members; we do not need, fortunately, to go afield beyond our own borders to find men, not only interested, but distinguished in every single department of engineering work. In fact, I suppose I may go so far as to say that it would be a surprise to us to find anyone who was really a leader in any branch of engineering who was not already one of ourselves. If any of you know of such a man, your obvious duty is to point out to him at once that his position is an impossible one, and that the sooner he comes into the fold the better, both for him and for us!

Judging from what I have seen of the programmes of business as they have been arranged by the officers of our different sections, there is no doubt that in every section of engineering matters of considerable interest as well as of importance are to be brought forward. It is interesting to notice, also, with how many matters which are not directly engineering our work brings us into contact:—with industrial questions, as in Lord Pirrie's Note on "Harbour and Dock Requirements;" Mr. Denny's on "The Problems of the Rand;" and Mr. Barrington's on "Light-Railway Policy." With chemical problems, in Notes on "Water-softening" and "Water-hardening." With metallurgy, in the Notes by Mr. Sandberg, Mr. Stead, and Mr. Blount. With biology, in Mr. Watson's remarks on "Sewage Disposal." With physics, in Mr. Mallock's Note on "The Action between Wheel and Rail," phenomena which are none the less very puzzling, because they are of everyday occurrence; and even with practical finance, in Notes on the cost of pumping and on the maintenance of machinery.

The division of our work into sections is, of course, made only as a matter of convenience, a mere matter of indexing. It has been

pointed out to me by a high authority—whose opinions we much respect—that the order of our sections is quite illogical. Clearly there were ships before railways—I suppose even before the Pyramids, and it is a question if there were not appliances which ought properly to be called "machinery" before either one or the other, so that in putting railways first, and machinery much later, in putting docks before ships, and in other respects, we have not followed anything like a chronological or even a scientific order. I think, perhaps, that the actual order in which the sections are placed may be justified, or at any rate explained, by the fact that this order corresponds very closely with that in which the subjects appear in our original Charter of 1828, if we are only willing to accept railways as the twentieth century substitute for the roads of Telford's time. It is strange, however, to think that in the whirligig of things there has come at this moment to be more discussion on the making, improvement, and maintenance of common roads than on any primary question connected with railway construction. At the time of our first Conference such a state of affairs would have been considered impossible; it might have been assumed that there was little to be said about permanent-way construction, but it would certainly have been taken for granted that there was nothing whatever to be dealt with in the matter of the making of roads. And yet to-day there are few questions which are more hotly discussed and about which there is more difference of opinion—a difference not merely among engineers, but affecting even the omniscient writers in the daily Press, to say nothing of their anonymous correspondents.

But again I wish to emphasize more the unity than the diversity of our work. I hope that members will not be so narrow-minded as to confine their interest and their presence to only those sections of the Conference with the business of which they are concerned in their everyday work. I should like to think that not only The Institution as a whole, but also its individual members, so far as their time and chances permit, has and have very wide interests. A gathering of this kind gives us all opportunities for hearing what our colleagues in different branches of engineering are saying and doing, and even for expressing our opinions on matters about which our colleagues may suppose—however wrongly—that we have, or ought to have, no opinions at all. I have no doubt that these opportunities, which do not occur so very often, will be taken full advantage of, and that we shall not be found to be confining our attendance and attention solely to the particular section of the Conference with which our everyday work specially identifies us. If, as engineers, we take an interest solely in railways or in dynamos,

in docks alone or in steam-engines only—or even in motor engineering, which some of our friends consider to cover all the other branches—we may be pretty sure that any such limitation of interest in professional matters will be a hindrance and not a help to that broadmindedness as citizens and as men of the world which we seek, at any rate in theory, to cultivate. By taking advantage of the wide area covered by the subjects of our different sections, we have a chance of finding out not only how far ahead of us are our friends who are working at our particular branch, but also how very interesting are all other branches of engineering, and how much more easy it is to form dogmatic, and doubtless accurate, opinions on other people's work than on our own—an excellent mental training and discipline for us all!

In asking you to proceed to the proper and subdivided business of the Conference, may I remind you of the scheme on which the business of the sections is intended or hoped to be carried out, which differs more or less from the ordinary routine of business at our Tuesday evening meetings. The Papers to be read are simply "Notes," strictly limited in length, and intended rather to open discussion and to promote it than to be any formal or complete statement of their particular subjects. It is expected that the reading of each note will occupy not more than 10 minutes or thereabouts. The opener being thus limited in time, the subsequent speeches will be similarly or still more limited, and the chairman of each section has, and will doubtless exercise, absolute and despotic authority over the duration of speeches, and will take care that they are not only brief, but to the point. There will be no time in the discussions for dealing with side issues or extraneous matters, and I am sure members will always support the chair in this as in other matters. At the close of each discussion the opener will be allowed a few minutes for reply.

The whole of the proceedings will be taken down verbatim, and printed as nearly *in extenso* as circumstances will allow. As, however, to be of any use to members, the printing must go on without delay as soon as ever the various proceedings are over, speakers who have any corrections to make in their remarks will be well advised to do so at once on receiving the proofs, as, if the Secretary does not receive them in a day or two, he will assume that the non-return of proofs implies that there are no corrections to be made in them.

I have now pleasure in declaring the Fourth Engineering Conference of The Institution of Civil Engineers to be in session, and of asking you to adjourn to the various sectional meeting-rooms, as to which full information is given in the programmes which are in your hands.

SUBJECTS DISCUSSED.

Section I.—Railways.

"The Chemical Composition of Steel Rails and Latest Development." Introduced by C. P. Sandberg.

"Reinforced Concrete for Railway Structures." Introduced by C. A. Harrison.

"The Best Means of Preserving Iron and Steel Work in Railway Construction." Introduced by Bertram Blount.

"The Action between Wheel and Rail." Introduced by H. R. A. Mallock.

"A System of Audible Signalling on Railways." Introduced by W. Dawson.

"Light-Railway Policy." Introduced by W. Barrington.

Section II.—Harbours, Docks, and Canals.

"Harbour and Dock Requirements as affected by Development of Shipping."[1] Introduced by The Rt. Hon. Lord Pirrie.

"Ferro-Concrete Structures." Introduced by C. S. Meik.

"The Durability of Reinforced-Concrete Structures." Introduced by F. E. Wentworth-Sheilds.

"Dock Equipment; including the Relative Advantages of Electric and Hydraulic Appliances." Introduced by W. W. Squire.

"Dredging in the Sea-Channels of the Mersey." Introduced by A. G. Lyster.

"Rock-Dredging, with particular reference to work at Blyth." Introduced by J. Watt Sandeman.

"Dredging Rock in the Suez Canal." Introduced by E. Quellennec.

Section III.—Machinery.

"The Turbine as applied to Marine Propulsion." Introduced by The Hon. C. A. Parsons.

[1] Discussed jointly with Section V.

"Reciprocating Engines for Ocean-going Steamers." Introduced by HENRY DAVEY.

"Precision Grinding." Introduced by H. DARBYSHIRE.

"Machine-Tool Design as affected by the Use of High-Speed Cutting Tools." Introduced by J. T. NICOLSON.

"The Use of Pneumatic Tools in Workshops." Introduced by C. P. WHITCOMBE.

"Reciprocating Air-Compressors." Introduced by W. REAVELL.

"Turbo-Compressors for High Pressures." Introduced by A. RATEAU.

SECTION IV.—MINING AND METALLURGY.

"Problems of the Witwatersrand Goldfields." Introduced by G. A. DENNY.

"Special Methods of Shaft Sinking." Introduced by HENRY LOUIS.

"The Design and Equipment of Shafts for Deep Winding." Introduced by C. E. RHODES.

"Arrangement and Design of Colliery Surface Works." Introduced by E. M. HANN.

"Segregation in Steel." Introduced by J. E. STEAD.

"The Education of Engineering Students, particularly with regard to Mining and Metallurgy." Introduced by WALTER ROWLEY.

"Electro-Metallurgy."[1] Introduced by BERTRAM BLOUNT.

SECTION V.—SHIPBUILDING.

"The Use of High-Tensile Steel in Compound Structures such as Ships, Bridges, etc."[2] Introduced by A. E. SEATON.

"High-Tensile Steel for Torpedo-Boat Construction."[2] Introduced by A. F. YARROW.

"The Use of High-Tensile Steel in the Construction of the 'Mauretania.'"[2] Introduced by E. W. DE RUSETT.

"The Structural Details of Cargo-Steamers in relation to their Water-Ballast Arrangements." Introduced by SAMUEL J. P. THEARLE.

"Arrangements for Working Cargo on Ships." Introduced by W. H. DUGDALE.

"High-Speed Vessels." Introduced by J. J. WELCH.

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[1] Discussed jointly with Section VII.
[2] " " " " IV.

"Modern Applications of Superheating to Marine Steam-Boilers." Introduced by A. SPYER.

"The Welding of Structural Materials in Place." Introduced by H. A. RUCK-KEENE.

SECTION VI.—WATERWORKS, SEWERAGE, AND GASWORKS.

"Comparative Cost of Pumping by Steam, Internal-Combustion Engines, and Electricity, based upon Actual Working." Introduced by CHARLES HAWKSLEY and HENRY DAVEY.

"Water-Softening." Introduced by WILLIAM MATTHEWS.

"Water-Hardening." Introduced by JAMES WATSON.

"The Applications of Towns Gas as a Heating Agent." Introduced by W. H. Y. WEBBER.

"The Distribution of Gas at Increased Pressure." Introduced by CHAS. C. CARPENTER.

"Sewage Disposal by Biological Processes." Introduced by JOHN D. WATSON.

"The Relative Merits of Chemically-Treated, Settled, and Septic Sewage, in preparing the Liquid for Oxidizing Beds." Introduced by G. A. HART.

SECTION VII.—APPLICATIONS OF ELECTRICITY.

"Modern Applications of Electricity to Mines."[1] Introduced by CHARLES P. SPARKS.

"Electrical Transmission-Gears on Motor-Vehicles." Introduced by A. A. CAMPBELL SWINTON.

"The Application of Electricity to the Working of Railway Points and Signals." Introduced by L. DE M. G. FERREIRA.

"Upkeep-Charges on Large Electric Generating-Sets." Introduced by H. R. J. BURSTALL and J. S. HIGHFIELD.

[1] Discussed jointly with Section IV.

VISITS TO WORKS.

WEDNESDAY, 19 JUNE.

Messrs. Crompton and Co.'s Works, Chelmsford.

Rotherhithe Tunnel and the Rotherhithe Hydraulic Power-Station.

Messrs. Yarrow and Co.'s Works, Poplar.

The Charing Cross, Euston and Hampstead Railway.

Messrs. Fraser and Chalmers's Works, Erith.

THURSDAY, 20 JUNE.

Woolwich Arsenal.

Chelsea Generating-Station, Underground Electric Railways of London.

The Gas Light and Coke Co.'s Works at Nine Elms.

Central Telephone Exchange, General Post Office.

National Physical Laboratory, Bushy House, Teddington.

FRIDAY, 21 JUNE.

Swindon Locomotive Works, Great Western Railway.

Admiralty Harbour Works, Dover.

Greenwich Electric Generating-Station.

Messrs. Siemens Brothers' Works, Charlton.

Deptford Electric Generating-Station.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 3662.*)

"Notes on the Natal–Cape Railway, particularly with regard to the Location and Setting-out."

By DAVID WILSON, B.E., Assoc. M. Inst. C.E.

THE Natal–Cape Railway is the Natal portion of a proposed intercolonial railway designed to give direct communication between Cape Colony and Natal. It was at first intended to serve an Imperial purpose at a time when the only railway connecting these two British Colonies lay through the South African Republic and the Orange Free State. While the preliminary negotiations and surveys were proceeding the Boer war broke out, and the subsequent annexation of the two independent States removed one argument in favour of a Natal–Cape Railway. It was never proposed, however, that the scheme should be abandoned on that account, as a railway through the native territories lying between the Great Kei River in Cape Colony and the Umkomaas River in Natal is much needed, both for purposes of administration and for trade. Therefore, in spite of engineering and financial difficulties, the agreement entered into by the two colonies 10 years ago continues in process of fulfilment, and Natal has, at a cost of about £842,000, constructed 95 miles of railway through a semi-mountainous country and has pushed the rail-head to within 13 miles of Riverside, the agreed point of junction on the Natal–Griqualand border.

In this Paper the Author presents a description of the principal topographical features of the country between Pietermaritzburg and Riverside, and of the methods adopted in the final survey and setting-out of the line.

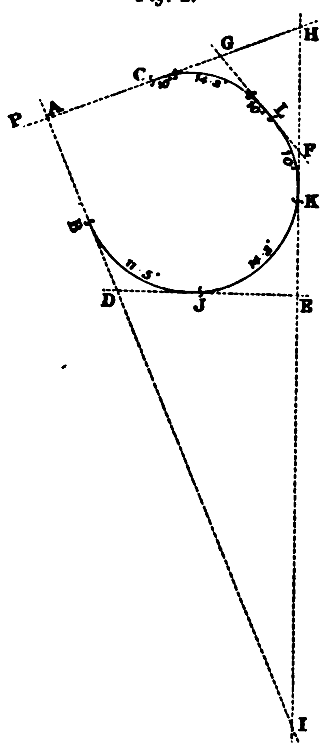
The Natal–Cape Railway joins the main line of the Natal Government Railways at Pietermaritzburg, the distance to Riverside being about 108 miles, Fig. 1, Plate 5. The route crosses the valley of the Umkomaas River, a barrier that cuts off the southern portion of Natal from easy communication with the rest of the Colony. The development that has been necessary in order to obtain the fairly easy maximum gradient of 1 in 40, and the difficulties in respect of

relative altitudes which had to be contended with, will be appreciated on reference to the plan and profile of the line, Figs. 1 and 2, Plate 5. That part of the line between the proposed Mondi Station at 98 miles and Riverside has not yet been decided upon. The greater part of the route lies along steep hillsides, intersected by gorges and running out into spurs, most of which had to be banked across or cut through at the expense of very heavy earthworks. The deepest cutting is more than 70 feet in depth and some of the embankments are more than 50 feet in height. Sidelong slopes of 30° are not uncommon, and at several places the formation has been cut out of the face of "krantzes." The main valleys and spurs have been negotiated by curves having a minimum radius of 400 feet, with the exception of a group of three curves of 300 feet radius. Many of these are horse-shoe loops running up to 266° of curvature and ½ mile in length.

In such a country very careful location is necessary if waste of money on earthworks is to be avoided. Care was especially called for when, as generally happened, these long curves on steep ground were laid out on the maximum gradient, and no balancing of earthworks was possible after the section had been plotted. Moreover, in order to follow as nearly as possible the contour of the ground, and to avoid frequent and sudden changes of curvature, compound curves had to be introduced. The setting-out of these long compound curves was one of the main features of interest in the work, and the methods employed will be explained by following in detail the location and setting-out of the loops at the upper crossing of the Sizananjan at 71 miles (Fig. 3, Plate 5). Advantage was taken of the fan-shaped widening out of the valley at the source of the Sizananjan spruit to double back against the contours and thus to gain M'Cejas Nek without introducing reversing stations. The length of this loop is 3,250 feet. The vertical height gained in that distance by a continuous compensated gradient of 1 in 40 is 66·5 feet. The horizontal distance between the ends is only 135 feet. The compound curve forming the crown of the loop was located and set out in the following manner:—The contour-plan had been already prepared from cross sections taken from traverse-lines. On this plan, by the process of plotting trial sections, the line which seemed to be the best in respect of both economy of construction and easy changes of curvature was laid down. The lengths B J, J K, K L, and L C (*Fig. 4*), components of the compound curve thus decided on, were carefully scaled from the plan, and the angles of curvature corresponding with these lengths were worked out. In the field the main tangents A G and A D were set out by offsets from

the traverse-lines, and the angle B A P was observed; as the sum of the angles of curvatures should be equal to 360° − B A P, one or more of these as found from the plan were altered slightly to make their sum equal to the observed angle. The functions of the component curves were then worked out for the angles thus corrected. All the angles of the polygon A D E F G and the lengths B D, D E, E F, F G, and G C being thus known, there only remained to be determined the lengths A B and A C in order to fix the position of the ends and set out the compound curve touching A B and A C. To determine the lengths A B and A C it is necessary first to solve the triangles D E I and F G H. The length H I will then be known, and hence the triangle H I A can be solved, and the lengths A B and A C found by subtracting the known lengths B I and C H from the lengths A I and A H respectively. The points A and B having been fixed by chaining from A, the intersections D, E, F and G were fixed by a traverse and the subsidiary curves were set out in the usual manner. The curve 'L C, although shown in *Fig. 4* as a symmetrical compound curve, has been treated as a simple curve. The method of doing this will be explained later.

Fig. 4.



The only extra work here involved has been the solution of three triangles, causing no appreciable delay in the field-work. It will thus be seen that a curve of at least four different radii can be set out with ease by this method. Abrupt and unnecessary changes of curvature are avoided, and the contour of the ground is followed as closely as the limiting curvature will permit. Compound curves were also introduced to flatten the ends of sharp curves and thus to act as transition curves. The maximum curvature was 14·3° per 100 feet, and instructions were issued by the Superintending Engineer of Surveys and Construction that at least 100 feet length

of a 10-degree or flatter curve was to be inserted at the ends of all curves sharper than 11·5°. The following is the method adopted of calculating the tangents of these symmetrical compound curves.

B P C (*Fig. 5*) is one-half of the simple curve. P C is to be replaced by the flatter arc P E and symmetrically at the other end. Given A C = T, the tangent of the simple curve, it is required to find A_c E, the tangent T_c of the compound curve.

$$T_c - T = DE + A_c F,$$

but
$$DE = OO_1 \sin\phi = R_1 - R \sin\phi,$$

and
$$A_c F = AF \tan\frac{\theta}{2} = EG \tan\frac{\theta}{2}$$

$$= R_1 - \{R + (R_1 - R)\cos\phi\}\frac{\sin\frac{\theta}{2}}{\cos\frac{\theta}{2}}$$

$$= (R_1 - R)(1 - \cos\phi)\frac{\sin\frac{\theta}{2}}{\cos\frac{\theta}{2}}.$$

Therefore
$$T_c - T = (R_1 - R)\left\{\frac{(1-\cos\phi)\sin\frac{\theta}{2} + \cos\frac{\theta}{2}\sin\phi}{\cos\frac{\theta}{2}}\right\}$$

$$= R_1 - R\left\{\frac{\sin\frac{\theta}{2} - \sin\left(\frac{\theta}{2} - \phi\right)}{\cos\frac{\theta}{2}}\right\}$$

$$= 2(R_1 - R)\sin\frac{\phi}{2}\left\{\frac{\cos\frac{\theta-\phi}{2}}{\cos\frac{\theta}{2}}\right\}.$$

This is a general expression for the increase in length of the tangent due to inserting an arc ϕ of radius R_1 at each end of a curve of radius R and angle θ. The coefficient $2(R_1 - R)\sin\frac{\phi}{2}$ can be worked out and tabulated for the cases required in practice, so that all that remains to be done in the field is to work out the ratio $\dfrac{\cos\frac{\theta-\phi}{2}}{\cos\frac{\theta}{2}}$

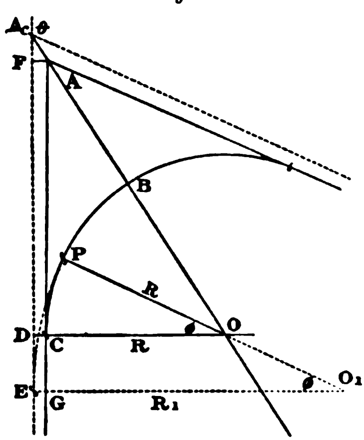
and multiply it by the constant taken from the prepared Table and add the product to the length of the simple tangent. In the only case of common occurrence on the Natal–Cape Railway, viz. inserting 100 feet of 10° curve at the ends of a 14·3° curve, this constant is exactly 30. As the ratio $\dfrac{\cos\dfrac{\theta-\phi}{2}}{\cos\dfrac{\theta}{2}}$ is greater than unity the process gave a lengthening of the tangents, and consequently of the curve at each end, of at least 30 feet, and seems to afford a good practical transition curve.

The distance to which it would be necessary to displace the tangent in order to leave the crown of the curve in the same position is

$$(R_1 - R) - (R_1 - R) \cos \phi = (R_1 - R)(1 - \cos \phi),$$

a quantity depending only on the radii of the curves and the length of the transition curve, and which can therefore also be tabulated if required.

Fig. 5.



The gauge of the Natal–Cape Railway is the standard South African gauge of 3 feet 6 inches. The maximum gradient is 1 in 40 on the straight, compensated on curves by 0·04 per cent. per degree of curvature. The choice of gradients lay between 1 in 40 and 1 in 30. The route at its worst places does not admit of an easier ruling gradient than the former, and there was no reason for suggesting a steeper gradient than the latter. Where sections of an easier gradient were possible, they were introduced as will be seen from the profile, Fig. 2, Plate 5. Where short reverse gradients occurred on a falling section, special care was taken to make them as easy as possible. Thus from Elandskop to Maritzburg the ruling gradient is 1 in 70, and to Umkomaas 1 in 60. Similarly from Binghams Nek to Umkomaas is 1 in 60, and to Umzimkulu 1 in 50. In some places great difficulty was experienced in obtaining a gradient of 1 in 40. This applies particularly to the section between Taylors Station and Elands River, a length of 25 miles, where a 1-in-30 gradient would

have shortened the route considerably. On the other hand, between Umkomaas and Binghams Nek, a length of 20 miles, in spite of the apparently artificial development that has been resorted to, the adoption of a 1-in-30 gradient would not have made any appreciable difference in the length. On one part of this section, namely, Sizananjan Station to M'Cejas Nek, a length of 5 miles and a horizontal distance of about 1 mile, with a rise of 570 feet, there is a loss of only 6 feet from the maximum gradient. Lowering of the level at the summit by 1 foot would have increased the cutting there by 600 cubic yards of hard shale, and raising it by 1 foot would have added similarly to the cost of the bank at Sizananjan Loop, half-way up. The adoption of a gradient of 1 in 30 between these points would have given a line covering practically the same ground, although a little might have been saved in the earthworks by breaking up the gradients. With regard to curves, the choice of a limit radius lay between 300 feet and 400 feet. Evidently in such a country the use of the smaller radius would have reduced the work considerably. On the other hand, the adoption of a limit curve appreciably flatter than 400 feet radius would have necessitated abandoning the route altogether. It will thus be seen that the gradients and curves which have been adopted are the best that the route admits of. The policy of making a better line than is necessary for present requirements was directed by the consideration that the Natal–Cape Railway is part of an intercolonial railway which may be reasonably expected to become an important route when the through connection has been made, and the resources of the country have been developed. This railway is now open for traffic to Creighton Station, a distance of 95 miles; the work of construction beyond that place has not yet been commenced. The magnitude of the work already done may be gauged from the fact that more than 2,700,000 cubic yards of earthworks have been paid for. The cost of transport of materials was a heavy item, and the need of a railway to develop the country is shown by the fact that the contract price for transporting a cask of cement by ox-wagon to Binghams Nek, before the first section was available for rail-transport, was 14*s*. 3*d*.

The Author is indebted to Mr. J. W. Shores, C.M.G., M. Inst. C.E., Engineer-in-Chief of the Natal Government Railways, for permission to publish the information contained in this Paper.

The Paper is accompanied by three tracings and two diagrams, from which Plate 5 and the Figures in the text have been prepared.

(*Paper No. 3595.*)

"Some Concrete Viaducts on the West Highland Railway."

By Walter Stuart Wilson, M. Inst. C.E.

The Mallaig extension of the West Highland Railway is 40 miles in length, and extends from Banavie, near Fort William, to the new pier at Mallaig on the Sound of Sleat. For about 12 miles the line runs for the greater part along the north shore of Loch Eil, and the works are light, the only structure of importance being the swing-bridge across the Caledonian Canal at Banavie. For the remaining 28 miles the line runs for the most part through a mountainous and rocky country, involving a great deal of rock-cutting, and comprises eleven tunnels and six viaducts.

Two of the viaducts are described in this Paper.

The rock on the route of the railway being mica-schist, quartz and gneiss—all very hard and difficult to dress—it was decided, before letting the contract, that, while the stone was admirably suited for concrete, it was quite impossible to use it for masonry on a large scale. Even supposing that the requisite number of men accustomed to work such stone could have been secured, the cost would have been prohibitive. Accordingly, almost all the bridges, the viaducts and the tunnel-lining are composed of concrete.

The Glenfinnan viaduct has 21 spans of 50 feet. It is on a 12-chain curve, and the extreme height is 100 feet. No difficulty was experienced with the foundations of the abutments and piers, some being on rock and others on bound gravel and mountain-clay. The whole viaduct was built in situ, and the proportions of the concrete used were, for foundations, 5 to 1; for abutments and piers, 4 to 1 with displacers; and for arches, 4 to 1. No sand was used in any of the concrete, the screens of the stone-breakers being regulated to give the desired proportions.

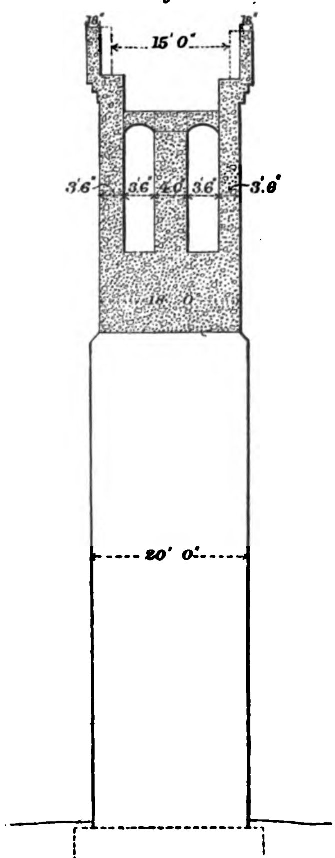
The piers (*Fig. 1*) are 6 feet thick at the top, with the exception of the two abutment-piers, which are 15 feet thick by 20 feet, battered 1 in 50 on the sides, but plumb on the ends. The arches, which are semi-circular in form, are 2 feet 6 inches thick, and provision is made, by the insertion at the crown of each arch of two ½-inch steel plates, for expansion, contraction, or any settlement of the piers (*Fig. 2*).

This plan has proved quite successful after 9 years' trial. Work was begun in July, 1897, and in October, 1898, the viaduct was ready for the conveyance of the contractor's materials across the valley. The cost of the viaduct was £18,904.

Other four viaducts, having from three to eight spans varying between 20 and 90 feet, were constructed on similar lines.

The Borrodale viaduct consists of three spans, the centre arch being segmental, of 127 feet 6 inches span and 23 feet rise, the others of 20 feet span (*Fig. 3*).

Fig. 1.



CROSS SECTION OF PIER
Scale: 1 Inch = 24 Feet

The large span springs from the solid rock on each side, and the extreme height is 80 feet. The arch, which is 4 feet 6 inches thick, is composed of 4-to-1 concrete, which was put on in layers, the top of each layer being left as rough as possible. After completion, a test-hole was cut in the arch to prove the solidity of the work; no trace could be seen of the joining of the different layers, and the concrete was perfectly homogeneous. In this viaduct no joints were made for expansion and contraction;

Fig. 2.

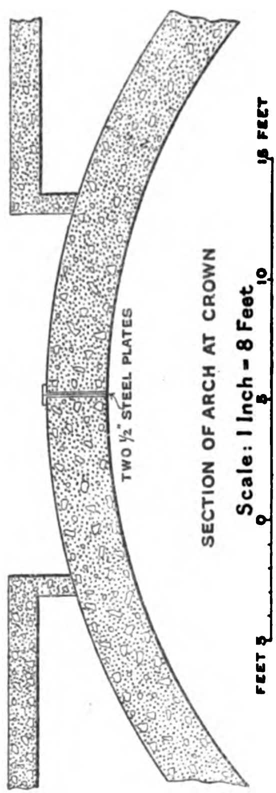
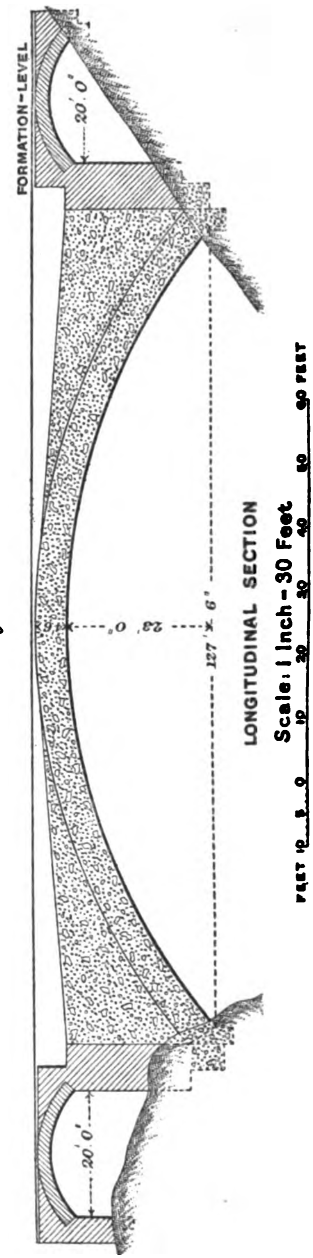

TWO ½" STEEL PLATES
SECTION OF ARCH AT CROWN
Scale: 1 Inch = 8 Feet
FEET 5 0 5 10 15 FEET

Fig. 3.


FORMATION-LEVEL
20' 0"
23' 0"
127' 6"
20' 0"
LONGITUDINAL SECTION
Scale: 1 Inch = 30 Feet
FEET 10 5 0 10 20 30 40 50 60 FEET

and the result has proved that in this case nothing of the kind was required. The arch shows no indication of movement of any kind, and is absolutely without a crack. The parapets and side spans were built of stone to satisfy the wishes of the proprietor of Arisaig Estate. The total sum paid to the contractor for this viaduct was £2,109.

The Paper is accompanied by two tracings, from which the Figures in the text have been prepared.

(*Paper No. 3718.*)

"A Rail-Section Tracing-Machine."

By HORATIO EDGAR DAWSON WALKER, Assoc. M. Inst. C.E.

THE cost of permanent-way renewals is one of the most important items in the maintenance-accounts of a railway-company, and it is essential that it should be kept at the lowest possible figure compatible with the assured safety of the travelling public.

When considering the renewal of any portion of the line the engineer is met by two difficulties. On the one hand, there is the possibility of an accident arising from too long a delay in removing worn and weakened rails; and, on the other hand, there is the necessity of avoiding the heavy expenditure, which at a low estimate may be taken as £1,500 per mile, before it is unquestionably required. The difficulty of coming to a decision is increased by facts of which the engineer has but an imperfect knowledge, and by circumstances over which he has no control. For instance, rail-steel, by whatever process manufactured, is far from being perfectly homogeneous. Again, such an accidental circumstance as a heavy downpour of rain occurring while the newly rolled rails are cooling on the "hot-bank" may seriously injure the physical properties of individual lengths. Chemical analysis cannot detect these defects, and the physical tests available may fail to disclose them. Moreover, it is impossible to detect the existence of internal flaws, and these may at any time become a grave source of danger should such a rail be seriously overstrained, as a girder, owing to careless packing of a sleeper.

To enable the engineer to come to a satisfactory decision, he should be in possession of the most complete data it is possible to obtain about an existing rail in respect to the position and amount of its worn area, so that he may be able to deduce its strength. Theoretically considered, the upper flange of a rail may be reduced by the wear due to the friction of passing traffic, until its area is equal to that of the original section of the bottom flange, and thus, in the last and weakest stage of such a rail, it would still be a correctly designed and safe girder. Such theoretical rail-wear,

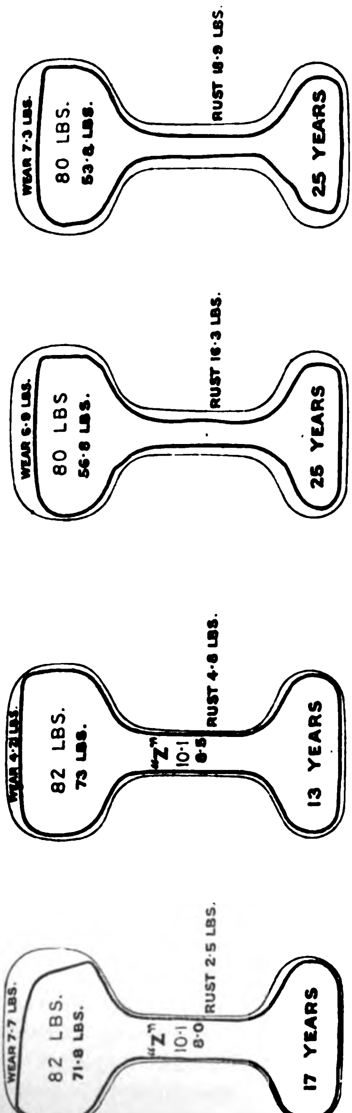
however, rarely if ever occurs, owing to the great effect of the atmosphere on its remaining surfaces. The wasting produced is rendered the more dangerous from the uncertainty of its amount and position. It is more particularly noticeable in tunnels, and railway-companies are now taking precautions to protect such rails by coating them with various compositions before they are laid down. There are, however, many situations outside tunnels where the atmospheric wasting is very serious, such for instance as near towns in manufacturing districts. This wasting is rendered the more insidious by the irregularity of its amount and by its position on the rail.

These irregularities are illustrated by some sections of worn rails taken by the Author (*Figs. 1*), which show not only the variability in position and amount of the wear but also the large proportion that the rusted area bears to the abraded area, in typical cases. No rules for the calculation of atmospheric wasting can be obtained, and, with the exception that the upper side of the bottom flange is often much more wasted than the web or the undersides of the flanges, there is no observable regularity in its amount and in its location. This want of regularity can no doubt be accounted for by accidental factors due to the situation of the rails, and by variations in the chemical composition of the surface of the metal. Thus it is impossible to determine any constant proportional value between frictional and atmospheric wear. The bottom flange is from the beginning the weakest part of a rail, hence any reduction of its area is a serious matter, and it should receive special attention and be very carefully observed and measured. The traffic wear of the upper flange of rails varies considerably, ranging from the one-sided wear of an outer rail on a curve, as shown by the first section in the Figure, to the almost uniform wear produced on a straight road as in the second or third sections. From the above considerations it is obvious that a reduction of weight is really no criterion of the amount of the reduction of the modulus of section and of the consequent diminution in the strength of the rail as a girder. This is exemplified in the first and second sections and also by the large number of worn rails tabulated, with their weights and moduli of section, in the Board of Trade report[1] on loss of strength in steel rails.

There are, in practice, various methods for ascertaining the wear and condition of rails in service. The Austro-Hungarian Government simply takes into account the diminution of height of the rail in determining the time for its renewal. This method is crude, and

[1] "Report of the Committee appointed by the Board of Trade to enquire into the Loss of Strength in Steel Rails through Use on Railways." London, 1900.

would, if practised with English girder-rails, tend to classify together rails of totally different strengths. The side wear on the outer rail in a curve would not be indicated, and the amount and location of atmospheric wasting would have to be assumed.



Figs. 1.

The practice of many of the leading English railway-companies is to weigh the rails, and to decide to renew when a certain minimum weight has been reached. This method has many disadvantages, not only as to the manner of ascertaining the necessary data, but also in the incompleteness of the information obtained. The position and quality of the worn surfaces are not ascertained, nor can the relative proportions of the two classes of wear be determined. A travelling gang of ten to twelve men is required to weigh the rails, and the operation requires a clear quarter of an hour to perform. The loss of time involved in waiting for such a suitable interval between trains on a main line in a busy district involves a serious expense, and the undesirability of taking out rails in running-lines, where delays to trains may result, need not be further emphasized.

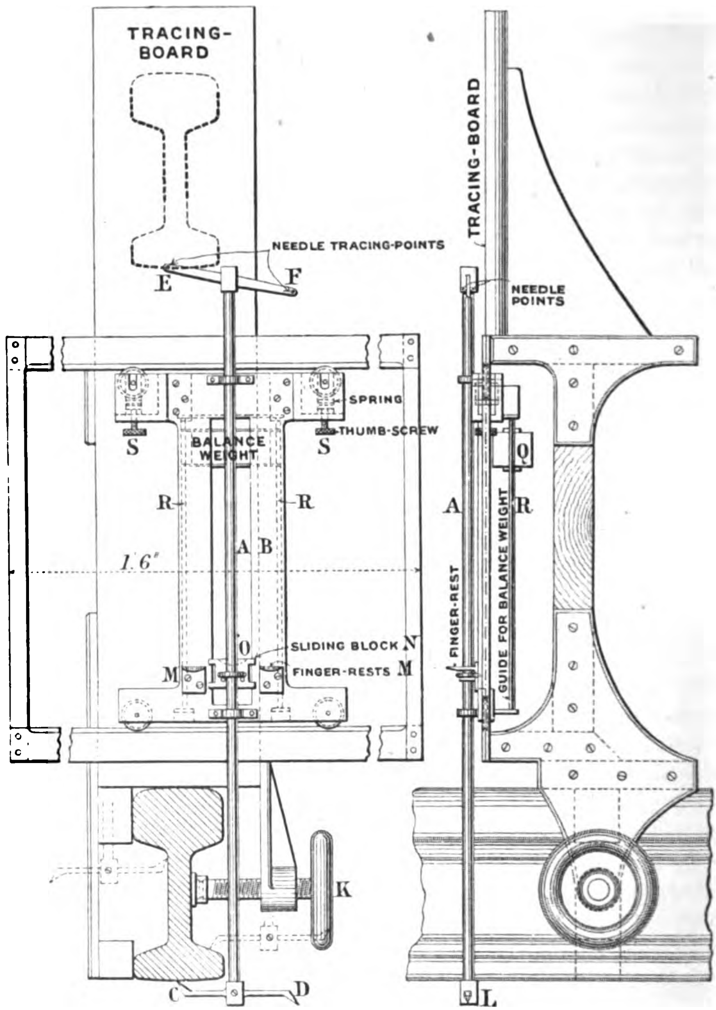
The only really scientific and satisfactory way of ascertaining the actual external condition of a rail in service which has deteriorated by wear and

wasting, is by obtaining its moment of inertia, as is done on the French Government railways, but to do this it is necessary to obtain the correct cross section of the rail. If this information be obtained at regular intervals, it will not only provide the desired data as to the strength of the rail from time to time, but will also afford a reliable guide as to the position and the rate of the wasting in progress, by means of which the exact time may be determined when its renewal will be necessary, provided the conditions of service remain comparatively constant. As the rate of deterioration may vary considerably on even a short length of railway, it is worth while logging the information obtained in the form of a continuous record.

Two methods have been frequently used to obtain these results, but both are clumsy and unreliable. The first is by taking plaster casts of the rail, but owing to the contraction of the plaster, these casts give a totally incorrect value of the sectional area of the rail; they do however indicate in some measure the irregularities of the frictional wear, and they give the ratio of the rusted area to the total wasting. The process of taking the casts is clumsy, and it requires unwieldy apparatus and several men to manipulate it. Waste of time in waiting for a suitable train-interval on busy lines is unavoidable, and traffic-delays may be caused. The second method, consisting in taking a rubbing from the end of the rail, is far more objectionable, because it not only requires the removal of the rail from the chairs, as in the case of weighing, but it also gives a totally incorrect idea of the true worn section of the rail itself owing to the deformation produced by the pressure of the fish-plates against the flanges and web. By the continual tightening of the bolts, the rail-surfaces in contact with the fish-plates become so abraded that all resemblance to the cross section of the remainder of the rail is lost. It is only at the centre of a rail that a typical and satisfactory section can be obtained, and the Author submits the description of a machine which he designed and used some years ago to trace such a section. In all essentials *Figs.* 2 represent the machine, as it was employed with satisfactory results, but they embody some detail improvements in the carriage and in the balance-weight attachment which the practical use of the machine showed to be desirable. The Author had originally designed a machine on the pantagraph principle, but the number and delicacy of the necessary joints formed an unsuitable feature for outside use, and he therefore adopted a simpler method of transmitting the necessary curved motions. Under the best of conditions the operator is awkwardly situated in obtaining a section, and whilst accurate results are required, delicate mechanism is out of place.

The machine consists of a rod A, having a free vertical and axial motion, and held by a carrier B, having a free horizontal motion. The bottom of the rod is fitted with a sharp-pointed bent steel cross

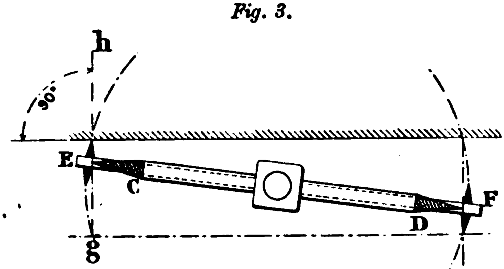
Figs. 2.



arm, CD; one of the sharp points (C) is bent upwards, and the other (D) downwards, so as to be able to follow the lower and the upper curves of the rail-section respectively. The top of the rod has a

cross arm EF, fitted with two hardened needle-points at each end which, when in contact with the paper affixed to the tracing-board, are adjusted to correspond with the position of their respective tracing-points below. This adjustment requires the lengths of the upper and lower tracing-arms to be different, as shown in *Fig. 3*, and the correct position is indicated by the line *hg*, being at right angles to the tracing-board and to the rail-section to be taken. The sliding block N (*Figs. 2*), in which the boss O of the tracing-rod can freely turn, is attached by a string, passing over a pulley to the metal box Q, placed between the guide-rods R R. The box Q is filled with lead to balance the weight of the tracing-rod and of the arms, thus relieving the operator, in his necessarily cramped position, from the small but inconvenient weight of the tracing-rod. The horizontal motion of the carrier is steadied by fitting the upper wheels to a

Fig. 3.



DETAIL OF TRACER

sliding axle-box, backed by springs, the pressure of which may be regulated by the milled head-screws S S (*Figs. 2*).

The first step is to well oil all round the rail where the section is to be obtained, so that the steel point may pass easily along the roughened surface of the worn metal. The machine is then clamped firmly to the rail by the wheel-screw K. The paper having been fixed on to the tracing-board by drawing pins, the operator, sitting across the rail and facing the front of the machine, takes hold of the boss L at the bottom of the tracing-rod with the right finger and thumb and guides the pointer (C) across the under surfaces of the rail, at the same time placing two fingers of the left hand on the finger rests M to assist and steady the horizontal motion of the carriage. With this pointer he follows both the lower curved surfaces and the web on one side of the rail. Then, by running the carrier to the end of its path, he can turn the rod round on its axis, as it is then clear of the tracing-board, so that the downward bent pointer (D) can be made to follow all the upper curves on that side of the rail, and

join up to the line already made for the vertical side of the web as indicated by lighter and darker dotted lines of the rail-tracing in the front elevation. By allowing the rod to rise to its highest position the carriage can be passed across to the other side of the rail, which can then be traced, thus completing a perfect diagram of the rail-section. The whole operation can be performed in 3 to 4 minutes.

The paper is then taken off the board, and the section traced in the office, and by being placed within the lines of the original section or previously obtained diagram, the position and quantity of the worn portion is immediately seen; the area can be obtained by a planimeter. The rate of wear can be valued from the time elapsed since the preceding operation, and the modulus of section can also be calculated.

The Author suggests, in order to obtain satisfactory data for determining the time for the renewal of any portion of a line, that the above operation should be repeated at 2-year intervals, at exactly the same position, on a typical rail fairly representing the conditions of situation, curvature, and gradient of each length relaid.

As it is essential that the needle-points of the tracer E F should not become worn, the Author experimented with various surfaces on which to make the tracing, and finally adopted a strong smooth drawing paper which he covered with a very thin layer of melted white wax mixed with lamp-black. A black surface was obtained which the needle-point easily and smoothly cut through, and the section of the rail thus appeared as a thin white line on a black ground. This proved quite satisfactory, as it prevented any scratching or tearing of the paper surface, and the section was easily traced afterwards.

The Paper is accompanied by two tracings, from which the Figures in the text have been selected.

(*Paper No. 3644.*)

"Survey of Inaccessible Places by Tacheometry."

By Otway Fortescue Luke Wheeler Cuffe, M. Inst. C.E.

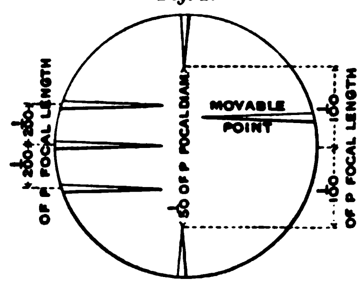
In the month of August 1905 the Author, during his furlough from Burma, was engaged by the Commissioners of Irish Lights to carry out a survey of the proposed site for a new lighthouse on the Great Skellig Island, 8 miles from the Kerry coast. Owing to the precipitous nature of the rock the survey would have been extremely difficult, if not impossible, by ordinary methods, and it was therefore decided to employ tacheometry. In this Paper the Author presents a description of the instruments used, and of the work done, to obtain all the necessary data for the construction of the new lighthouse, and for the removal of portions of the cliff, both on the western and southern headlands of the island, in order to obtain the maximum arc of illumination.

Instruments used.—The tacheometer used was of the most modern form, with various improvements designed by Mr. C. W. Scott, B.A.I., Assoc. M. Inst. C.E., the Engineer to the Board, and was made to his order by Messrs. Stanley and Company. The following is Mr. Scott's description of the instrument:—

"It has a diaphragm fitted with five fixed platinum-iridium points, which are much more satisfactory than webs or lines engraved on glass. Three points on one side of the diaphragm are horizontal, two of them being fixed $\frac{1}{200}$ part of the principal focal length of the object-glass above and below the axial point, and two vertical axial points are fixed with their extremities $\frac{1}{50}$ of the same distance apart, and each $\frac{1}{100}$ of the same distance from the horizontal axial point (*Fig. 1*). On the other side of the diaphragm is a movable point which can be traversed over the height of the diaphragm by a micrometer-screw, every complete turn of which moves the point over a distance equal to $\frac{1}{1,000}$ of the principal focal distance; and the head of the micrometer being divided into one hundred parts, it reads to $\frac{1}{100,000}$ of the same, while a small

star-wheel records the number of complete revolutions, five of which cover the space between any two of the fixed points. The telescope is a plain open one with an object-glass of 14½ inches principal focal length, fixed 8 inches in front of the axis; the constant to be added to all stadia and micrometer distances is therefore 1·9 foot or 2 feet. There are many advantages in the use of a plain, open telescope instead of an anallatic one as generally used on tacheometers. Amongst them the following may be mentioned:—more light reaches the eye because there are fewer lenses; there are no intermediate lenses requiring adjustment on an accurately measured base; with a telescope of the same dimensions greater power can be obtained; and there are fewer lenses to be kept clean. The idea which appears to be still common that an ordinary open telescope will not give accurate results at all distances by means of stadia-readings plus the distance of the anterior principal focus of the object-glass from the axis of the instrument, is entirely erroneous. Both the horizontal and vertical arcs are divided into 360° and decimal parts of a degree. The decimal division of the degree greatly facilitates the calculation compared with that required with the sexagesimal division into minutes and seconds, and the reading of the verniers is much simpler and less liable to error. Any instrument divided sexagesimally can be converted by simply changing the vernier if the divisions on the limb are degrees or half degrees."

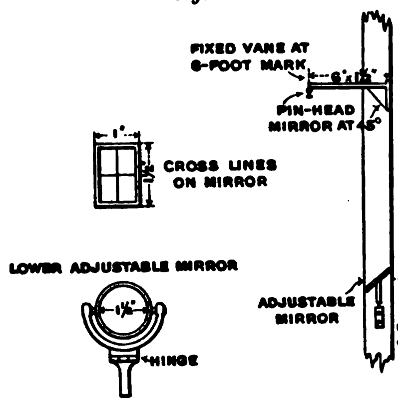
Fig. 1.



The staff was an ordinary levelling-staff 16 feet in length. Exactly at the 6-foot mark a sighting-vane, painted red on the top side and white on the underside, was fixed to the side of the staff and clamped in a position truly normal to its face. This vane enabled the observer at the instrument to ascertain whether the staff-holder was holding the staff truly normal to the line of sight, and it was fixed at the 6-foot mark to form the centre of the 10-foot target, the 11-foot and 1-foot marks forming the top and bottom of the target respectively. A simple arrangement of reflecting mirrors, capable of being fixed in slots on either side of the staff as found convenient, enabled the staff-holder, whatever his height, to align the vane on to the tacheometer, and consequently to ensure the staff being at right angles to the line of sight. The upper mirror is fixed

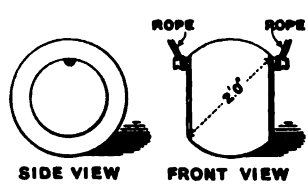
and inclined at an angle of 45°, with horizontal and vertical lines cut on it, as shown in *Figs. 2.* At the outer end of the vane a common pin is fixed in a socket and is adjusted so that the head of the pin is the same distance below the vane as the intersection of the cross lines on the inclined mirror. The lower mirror consists simply of a small circular mirror in a frame, capable of being turned to any desired position, to enable the staff-man to see reflected in it (*a*) the cross-lines of the upper mirror, (*b*) the pin-head, and (*c*) the telescope of the tacheometer. When these three objects are observed to coincide in the lower mirror, the staff is in the desired position for taking a reading; namely, normal to the line of sight. The mirrors are reversible to enable a staff-holder standing on higher ground than the staff to observe with equal ease. The 10-foot target previously referred to is formed by clamping cross-bars to the staff at the 1-foot and 11-foot marks, the sighting-vane at the 6-foot mark then forming the centre of the target. The cross-bars are about 10 inches in length and $1\frac{1}{2}$ inch in width and are painted to correspond with the black and white graduations of the staff, to which they are fixed by means of thumb-screws.

Figs. 2.



The sphere, for sights in positions on cliffs which were inaccessible to the staff-holder, was 2 feet in diameter and consisted of a hollow wooden frame-work covered with $\frac{1}{4}$-inch planking very carefully tongued and grooved together, and painted white. For lightness and to enable ropes to be passed through it, the sides were cut away, leaving two openings each 1 foot in diameter (*Figs. 3*). It was found most convenient to attach two light ropes to the sphere as shown in *Figs. 3;* two men on different points of the cliff were thus enabled to adjust the sphere to the position required.

Figs. 3.



Methods of Using the Instruments.—By means of these instruments

readings could be taken by the following three different methods, each independent of the others, and useful in many cases for checking one another.

First Method.—Using a 15-foot graduated levelling-staff; suitable for all distances up to 400 feet. The staff being held normal to the line of sight, the axial hair of the telescope is directed to read exactly 6 feet on the staff. The upper and lower stadia-points are also read and booked, and for important stations, the readings of the vertical points as well; their difference is divided by 2 to obtain the height on the staff, which is $\frac{1}{100}$ of the distance. The distance, S, of the staff from the axis of the instrument is then

$$S = \frac{F(m-n)}{i} + F + c$$
$$= 100(m-n) + F + c, \text{ or } \frac{100(m-n)}{2} + F + c$$

according as the $\frac{1}{100}$ or the $\frac{1}{50}$ stadia-points are used; where m denotes the upper stadia-reading, n the lower stadia-reading, F the focal length of the object-glass, i the distance between the stadia-points, c the distance of the object-glass from the axis, and the constant $(F + c)$ is 1·9 foot (say 2 feet) in the case of a $14\frac{1}{2}$-inch telescope.

Second Method.—Using the 10-foot target; suitable for distances exceeding 400 feet. The axial point is directed as before to the centre of the target, viz., the 6-foot mark on the staff. The vertical circle is clamped and the angle is read off. By means of the vertical arc tangent-screw, the nearest fixed stadia-point is brought to the top or bottom cross-bar, and the movable micrometer-point can then be brought to the other cross-bar by means of the micrometer-screw. The micrometer-reading is the reading on the divided head, plus 500 for each complete scale-division included between the fixed points. The fixed point is then set to the lower or upper mark on the target, according to whether the micrometer reads upwards or downwards. The distance from the axis of the instrument is

$$S = \frac{100{,}000\ L}{x} + F + c,$$

where x is the micrometer reading, L, the length of the target, $= m - n$, and c the distance of the object-glass from the axis. Mr. C. W. Scott has recently published Tables[1] giving this calculation

[1] C. W. Scott, "Tables of Sines and Cosines, for the Reduction of Tacheometric Observations." London, 1905.

for distances from 400 feet to 2,000 feet with a 10-foot target; these Tables can be used for any distance or any size of target by dividing or multiplying the results proportionately.

Third Method.—Using the sphere in inaccessible places. Exactly the same method is adopted as with the 10-foot target, the sphere becoming a 2-foot target. The Tables above referred to are then used, and the results obtained are divided by 5; the constant to be added of course remains the same. The spherical shape was adopted, as it always presented a diameter of 2 feet from whatever angle it was observed, which would not be the case with a staff, however carefully suspended. So far only S (the distance of the staff or target from the axis of the instrument) has been found. The true horizontal distance and the vertical height above or below the instrument are given by the following formulas:—

Let h denote the reading of the axial point, A the horizontal distance, B the vertical distance above or below the instrument, a the reading of the vertical limb in degrees, and S the distance by station or micrometer:

Then
$$A = S \cos a + h \sin a$$
$$B = S \sin a - h \cos a$$

when a is positive, *i.e.* above the instrument.

Or
$$A = S \cos a - h \sin a$$
$$B = S \sin a + h \cos a$$

when a is negative, *i.e.* below the instrument.

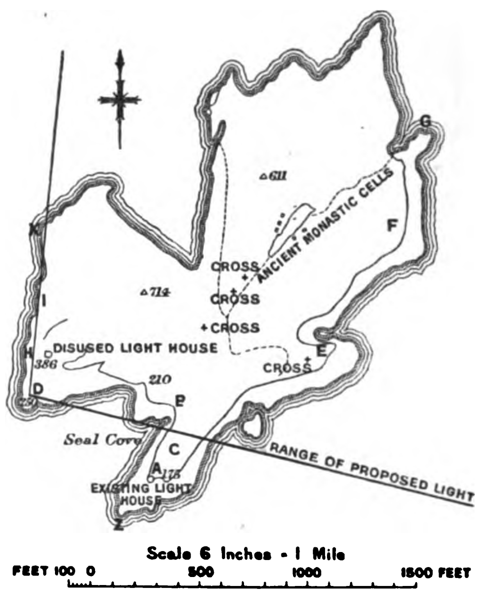
$h \sin a$ is a negligible quantity at small angles.

In the Tables referred to, the values of sin a and cos a multiplied by any number are given to the third decimal place, and the decimal division of a degree corresponding to any number of sexagesimal minutes and seconds are also given. A specimen-page of the field-book used is given as an Appendix to the Paper.

Survey of Great Skellig Island.—The Great Skellig Island is about ½ mile in length, and ¼ mile in width, the highest pinnacle rising to a height of 714 feet above sea-level, *Fig. 4.* On the western cliff, 386 feet above sea-level, stands the ruin of an old lighthouse abandoned more than 30 years ago in consequence of its being so often fog-capped. The existing lighthouse is on the southern side, with its focal plane 175 feet above the sea; it is of an obsolete pattern and does not command a sufficiently large arc. For the new tower a position had to be selected which would enable it to light from Dunmore Head (the mainland side of the Blasket Sound) on the north, to Cod's Head on the south, or if possible even farther

round, up the Kenmare River, *Fig. 5*. It will be seen by reference to *Figs. 4* and *5* that there was only one possible position for a new lighthouse to fulfil these conditions, viz., at the farthest point seaward of the south-west headland at which secure foundations could be obtained. It therefore remained only to ascertain the exact site which would require the minimum amount of blasting of the intervening headlands in order to obtain the desired arc of illumination. To do this, exact contours had to be obtained northwards and eastwards on rocks rising steeply from deep water. These contours were taken from low-water level up to more than 300 feet above

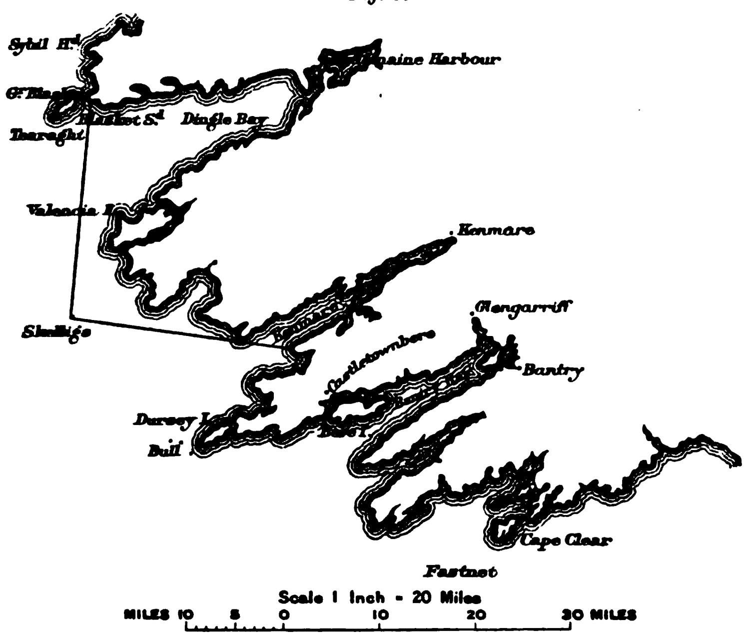
Fig. 4.



it, over the whole area from X to Z on the plan, *Fig. 4*. In the vicinity of the proposed site, D, 250 feet above the sea, and on the headlands H, I and C, contours were drawn 10 feet apart; elsewhere they ranged between 20 feet and 50 feet apart; stations were selected on points of the cliff where it was possible to erect the tacheometer. Station A was on the gallery of the existing lighthouse, and it was from this initial point that the meridian was fixed by taking sights on the Bull Rock Lighthouse and other prominent and well-defined headlands on the mainland, and checked by astronomical observations. In addition to this

work, a survey was made from the landing-place at G, along the road more than a mile in length which leads up to the old lighthouse. Points were first fixed by means of the tacheometer from the main stations A, B, C, E, F, and G, and a chain-survey was made from point to point. In the fourteen working days about four hundred readings were taken, of which more than one-half were on inaccessible points. Observations on these points were quickly and accurately taken by lowering the sphere down the cliff or slinging it across chasms. To make the observations by means of an ordinary

Fig. 5.



theodolite would have required an elaborate system of ropes and ladders, and would have occupied several months, not to mention the risk to human life which would have been incurred. Great assistance was rendered by the lighthouse-keepers, particularly by semaphoring orders which could not be given verbally on account of the roar of the breakers and the wind. With regard to the accuracy of the readings, it was found that the error was less than 1 per cent., both for horizontal and vertical distances where the 2-foot sphere was used; the longest sight taken was 931 feet, but in order to ensure accuracy the average distance was not more than 500 feet.

A general plan, with contours, was plotted to a scale of 50 feet to 1 inch, each tacheometer reading being shown, with its height above datum; and detail-plans, to a scale of 10 feet to the 1 inch, were made of the headlands on which the stations D and C were situated. The Author desires to express his indebtedness to Mr. Scott, for permission to make extracts from his work, previously referred to, on "Tables for the Reduction of Tacheometric Observations."

The Paper is accompanied by a tracing and three drawings, from which the Figures in the text have been prepared; and by the following Appendix.

APPENDIX.

Specimen-Page of Field-Book.

Instrument Station.	Staff Station.	Horizontal Limb θ	Vertical Limb a	Stadia Readings m, n.	Micrometer Reading x	Distance $100\,(m-n)\,F+F+c$ or $\frac{100{,}000\,l}{x}+F+c$	Axial Point Reading h	Horizontal Distance $S\cos a \pm h\sin a$	Height $S\sin a \mp h\cos a$	Height above Datum. Optical Axis.	Height above Datum. Station	Remarks.
A	81	38·83	+29·50	{6·73, 5·29} {7·45, 4·59}	..	145	6·0	129·25	+ 66·22	199	265·22	Same as 80 west point.
	D	298·15	+ 6·52	{9·10, 2·95}	10 ft. staff 16·63	Mean 615	6·0	611·37	+ 64·16	,,	263·16	Check readings.
	82	301·60	+ 6·45	..	16·85	595	6·0	592·1	+ 60·68	,,	259·68	Inner corner of D ledge.
	83	295·23	−19·26	Sphere	4·12	487	0	459·72	−160·71	,,	38·29	Near water-level on E side under site.
	84	296·81	−13·55	,,	4·00	502	0	487·94	−117·46	,,	81·56	Same higher up.
	85	299·09	− 7·64	,,	3·95	506	0	501·44	− 67·30	,,	131·71	,, ,, ,,
	86	302·04	− 1·47	,,	3·66	549	0	549·00	− 14·27	,,	184·73	,, ,, ,,
	87	328·61	+ 9·88	{3·25, 8·85}	10 ft. staff 17·90	562	5·4	554·42	+ 91·20	,,	290·2	Along ledge from first zigzag.
	88	324·12	+10·46	{3·08, 8·96}	17·50	Mean 582	6·0	573·18	+ 99·34	,,	298·34	Ditto against wall of road.
	89	288·89	−12·78	Sphere	3·80	528	0	514·80	−116·68	,,	82·32	Near water-level near end of point.

(*Paper No. 3707.*)

"Concrete-Cylinder Sinking at Haulbowline."

By Harry Ekermans Oakley, M. Inst. C.E.

The purpose of this Paper is to describe the sinking of some concrete cylinders at H.M. Dockyard, Haulbowline, Cork, to form the foundations for a berthing-jetty intended to facilitate the movement of battleships to and from the basin.[1] The extent and character of the work is shown in *Figs. 1*. The jetty was designed to allow dredging alongside to a depth of 24 feet at L.W.O.S.T.

Before the contract was made, borings were taken on the site of each row of cylinders, from which it was ascertained that the material to be passed through was silt of considerable stiffness when in situ, but which readily fell into slurry under the influence of water. This silt was overlaid to a depth of 2 or 3 feet with quarry-tippings, but once these were passed through, no further obstruction was found except at the eastern end of the jetty, where, at a depth of 60 feet below the coping, pieces of timber were met with.

The first step in executing the work was to dredge away the rubble overlying the silt, as indicated in *Figs. 1*. This was done with a side-ladder dredger, discharging into sea-going hopper-barges. At the completion of the work the new foreshore was protected with a coating of rubble 2 feet thick. The abutment at the eastern end of the jetty was constructed by forming a dam of whole-timber sheet-piles driven down to the rock. The material inside the piles was removed by grabs, and was replaced by concrete lowered through the water in skips; the composition of the concrete was 4 of stone broken to pass a $1\frac{1}{2}$-inch ring, $1\frac{1}{4}$ part of sand to 1 of Portland cement. In removing the material, several trunks of trees

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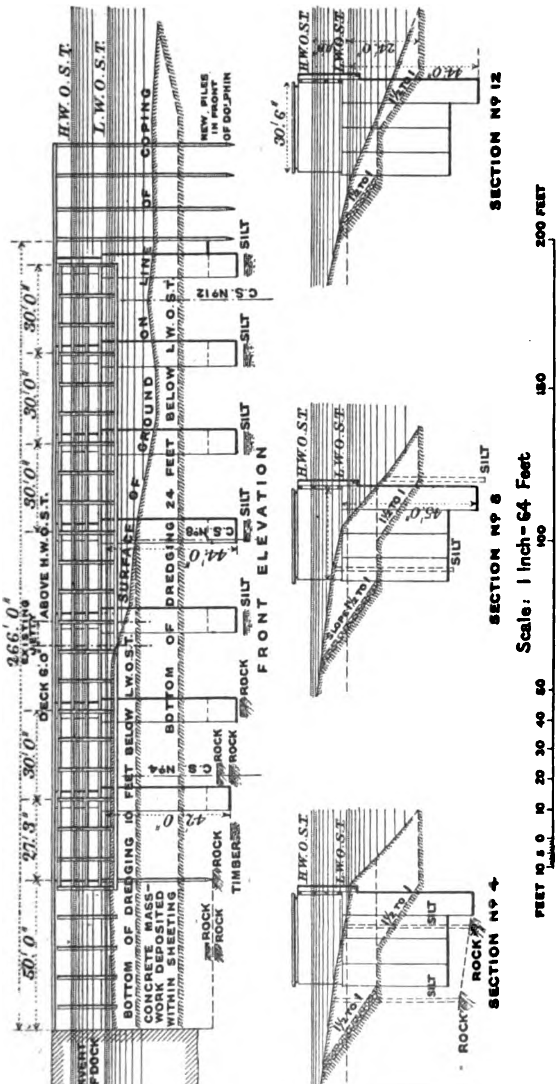
[1] A description of the sinking of cellular brick caissons near this site in 1878 is contained in the Paper, by Mr. C. Andrews, "On the Use of Cellular Caissons." Minutes of Proceedings Inst. C.E., vol. lxiv, p. 321.

were found resting on the original bed of the harbour at a depth of 45 feet from the present mud-level.

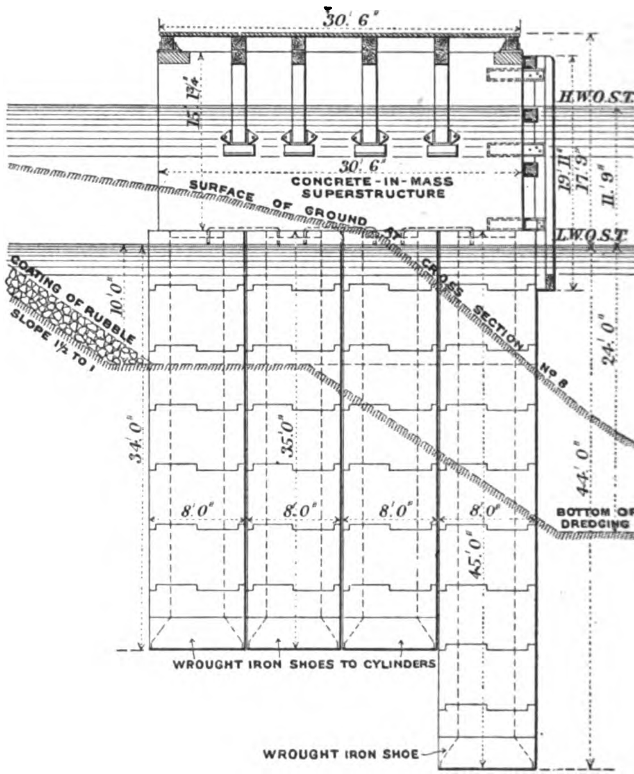
Figs. 1.



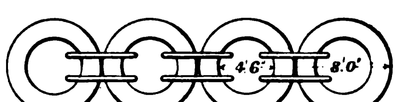
Each cylinder, for the foundations of the remainder of the jetty, consisted of a number of concrete rings 8 feet in external and 4 feet 6 inches in internal diameter and 5 feet long, the top and bottom

surfaces being joggled to fit into one another (*Figs.* 2). The composition of the concrete for these cylinders was the same as given already for the concrete abutment. These rings were made in

Figs. 2.



CROSS SECTION OF CYLINDER PIER



PLAN AT TOP OF CYLINDERS SHOWING RAIL CLAMPS

Scale: 1 Inch = 16 Feet

FEET 10 5 0 10 20 30 FEET

wooden moulds on a timber platform; the staves of the outside casing were screwed to angle-bars so that the two halves of casing could be secured together with jibs and cotters. The rings were

allowed to remain in the mould 7 days, and were not lifted until 21 days after the removal of the moulds. The bottom ring of each cylinder was provided with a steel shoe. Whole-timber piles were driven to a depth of 8 feet below the mud-line around the intended position of each pier, and were secured together with braces and walings, which acted as guides in sinking the cylinders. The highest guide was 6 feet and the lowest 13 feet below the deck level. These timber piles also carried a gantry for handling the rings.

The bottom having been levelled by divers, the first ring carrying the shoe was lowered and set level, then rings were added until they reached the deck-level. At first the rings were placed on one another without any bedding, but the weight required to sink them, combined with the shock caused by "runs," caused several of them to crack slightly in a vertical direction. It was therefore decided to bed them in neat cement some days before they were required, the under surface of the upper ring being greased to prevent the cement from adhering. The rings were marked so that they could be lowered into place in the same relative position as when bedded. If rings were used temporarily as a driving load they were bedded on two thicknesses of tarred felt. When the rings reached the deck-level the silt inside the cylinder was removed by means of single-chain grabs, worked from cranes travelling on the temporary staging, and in order to cause the cylinder to subside, pig-iron was placed on top, to overcome the frictional resistance. A schedule was prepared from measurements taken three times a day, giving the weight of pig-iron required and the time taken in sinking. In order that these figures might represent as nearly as possible the resistance due to friction only, all cases in which the grab was less than 1 foot in advance of the shoe have been omitted. The average resistance when the mud was about level with the bottom of the shoe amounted to 5·9 cwt. per square foot of the surface in contact with the mud. At first pig-iron ballast, about 4 inches by 4 inches in section and 3 feet long, was used for loading, but this size was found difficult to pack conveniently and the contractor afterwards had some castings made, 9 inches by 9 inches in section and 9 feet long, which could be symmetrically placed, and which left sufficient space in the centre for working the grab. In most cases the cylinder sunk slowly and regularly, the rate depending to a considerable extent on the amount the grab was in advance of the shoe. If the advance was less than 3 or 4 feet a distinctly greater resistance was observed, due to the support given by the material under the splayed part of the shoe which the grab was unable to reach. The friction per square foot of surface did not appear to increase with the depth.

It will be seen by reference to Mr. Andrews's Paper[1] that the frictional resistance met with in sinking his brick cellular caissons amounted to somewhat less than 2 cwt. per square foot of surface in contact. The average, in the case of the concrete cylinders, is 5·9 cwt. per foot. This difference in favour of the brick caisson on a timber curb is at first sight somewhat surprising, but the explanation would appear to be that: (1) The silt, in the case of the brick caissons, was in a disturbed state on account of the purging caused by the weight of the backing to the adjoining cofferdam. (2) In the brick caisson it was possible to excavate under the curb, whereas the material under the splayed shoe of the concrete cylinder could not be reached by the grab, and it afforded some additional support. (3) The general advantage that large caissons or cylinders have over small ones, an advantage which has been noted in other cases.[2] In sinking some of the cylinders, balks of timber were met with, which had to be cut away by divers, and the "runs" occurred chiefly in connection with the removal of these timber obstructions. In no case did the "run" exceed 6 feet and the cylinder dropped vertically and without disturbing the load. It was found necessary to work day and night in order to complete the work as near the contract date as possible. The sustained work was found to considerably facilitate sinking the cylinders, as the continuous movement prevented the material from settling around the cylinder and so increasing the friction. The silt also rose inside the cylinder in some cases if left for any time.

In order to allow for adjustment of level, the top rings on each cylinder were not made until after the column had been sunk and passed by the Engineer-in-Charge. In some cases, due to "runs," the cylinders were sunk several feet more than was required by the contract-drawings. The cylinders were filled with concrete composed of 5 parts of broken stone, 1½ part of sand to 1 of Portland cement. It was specified that a test load of 100 tons was to be applied on each cylinder after sealing the bottom with 4 feet of concrete, but the weight required to sink the cylinders was in most cases considerably more than this, rendering testing unnecessary. The silt removed from the dam and the cylinders was discharged into trucks and tipped for foreshore reclamation. The superstructure was of American pitch-pine timber, creosoted with 3½ lbs. of creosote oil to each cubic foot of timber. All bolts, washers, and other ironwork were coated with Dr. Angus Smith's composition.

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[1] Minutes of Proceedings Inst. C.E., vol. lxiv, p. 321.

[2] *Ibid*, vol. liv, p. 113; and vol. ci, p. 39.

The plant used by the contractor, in addition to the gantry commanding the whole of the work, included two 3-ton traveller cranes for working the grabs and a 15-ton travelling derrick-crane with a maximum radius of 42 feet. The grabs used, which ranged in capacity from $\frac{1}{8}$-yard to $\frac{1}{4}$-yard, were all single-chain grabs of well-known types. It was found that the Wild grab did better work without the cylindrical guide fitted for use in cylinder-sinking. This guide caught on projections inside the cylinder and also offered considerable resistance to the rapid descent of the grab through the water. Owing to the comparatively small inside diameter of the cylinders, the grabs were small, and had not enough weight to penetrate the stiff material sufficiently to get very good results, and the work was considerably delayed.

The work was done on a lump sum contract of £17,000. The time allowed was 20 months, which was exceeded by 11 months, due to delays in commencing work.

The jetty was designed under the direction of Colonel Sir Edward Raban, K.C.B., R.E., Director of Works of the Navy; the Contractor was Mr. John Best, of Edinburgh; the Author acted as Resident Engineer.

The Paper is accompanied by three sheets of drawings from which the Figures in the text have been prepared; and by the following Appendix.

[APPENDIX.

APPENDIX.

SCHEDULE SHOWING THE FRICTIONAL RESISTANCE OVERCOME IN SINKING CONCRETE CYLINDERS 8 FEET IN DIAMETER THROUGH SILT.

All cases in which the grab was not in advance of the shoe were eliminated from the records.

Number of Cylinder on Plan.	Maximum Frictional Resistance per Square Foot of Surface in Silt.	Depth of Cylinder in Silt when Maximum Resistance took place.	Amount the Grab was in Advance of Shoe.	Average Frictional Resistance per Square Foot of Surface in Silt.	Time taken in Sinking Cylinders.	Remarks.
	Cwt.	Feet.	Feet.	Cwt.	Days.	
A1	6·3	26·9	1·6	5·7	57	Timber met with.
2	10·0	36·9	1·0	6·7	57	The work on these cylinders was intermittent gravel mixed with silt.
3	6·9	23·3	5·4	6·5	76[1]	
4	6·5	24·8	5·8	5·8	64[1]	
B1	6·8	13·7	2·0	5·3	21	
2	4·9	24·10	6·6	4·2	4	
3	5·6	24·8	6·8	5·3	14	Working day and night after 18 July, 1899.
4	6·8	12·0	1·6	5·6	16	
C1	4·7	23·2	1·0	4·7	6	
2	5·5	23·0	1·0	5·5	6	
3	6·2	17·0	1·4	5·7	5	
4	6·3	18·9	2·6	5·7	10	
D1	5·6	12·4	1·0	4·7	5	
2	..	..	..	..	..	Grab not in advance of shoe.
3	9·70	5·2	1·5	5·2	66	
4	8·44	6·9	1·0	6·0	12	
E1	8·00	8·6	1·8	5·3	23	
2	10·40	11·4	2·6	8·5	11	
3	10·67	5·7	1·0	6·0	30	
4	10·53	5·9	2·7	6·6	28	
F1	8·15	9·6	1·1	6·0	10	
2	16·53	3·11	1·0	8·6	13	
3	12·29	4·9	0·8	7·1	7	
4	6·06	12·4	2·0	5·0	12	
		Average . . .		5·9	21	

[1] Gravel mixed with silt.

(*Paper No. 3723.*)

"Removal of Subaqueous Rock at Blyth."

By GEORGE DUNCAN McGLASHAN, Assoc. M. Inst. C.E.

THIS Paper has reference to a recent development of a method of removing subaqueous rock, adopted for the work now in progress at Blyth Harbour, Northumberland. In 1906 the Blyth Harbour Commissioners decided to carry out an extensive scheme of improvement, and among the works embraced in the scheme was the deepening of the harbour to 24 feet at low water of spring-tides, involving the removal of about 500,000 cubic yards of rock. For this purpose it was decided to employ a Lobnitz rock-breaker, and so successful were the results that a second machine was obtained this year (1907).

This method of rock-breaking consists in the repeated blows of a long heavy pointed chisel or ram, which falls by its own weight upon the rock to be broken. No explosives are required. The machine consists of a barge upon which stand the tripod legs supporting the ram, a winch for hoisting the ram by means of a wire-rope led over a sheave at the top of the tripod, another winch for operating the chains that manœuvre the barge, an ordinary marine boiler for supplying steam to the winches, and smaller supplementary machinery and plant.

Information will be found respecting some early machines in the Proceedings,[1] but considerable progress has been made in late years in the improvement of the machinery and appliances, and the rock-breaker here described is representative of the latest type (*Figs. 1*).

The barges of the rock-breakers at Blyth are of steel and measure 100 feet by 28 feet by 8 feet, and they are divided into five water-tight compartments, one of which serves as a fresh-water tank for the boiler-supply, and the others are utilized for cabin-accommodation for the crew and for the storage of reserve wire-ropes, chains, etc.

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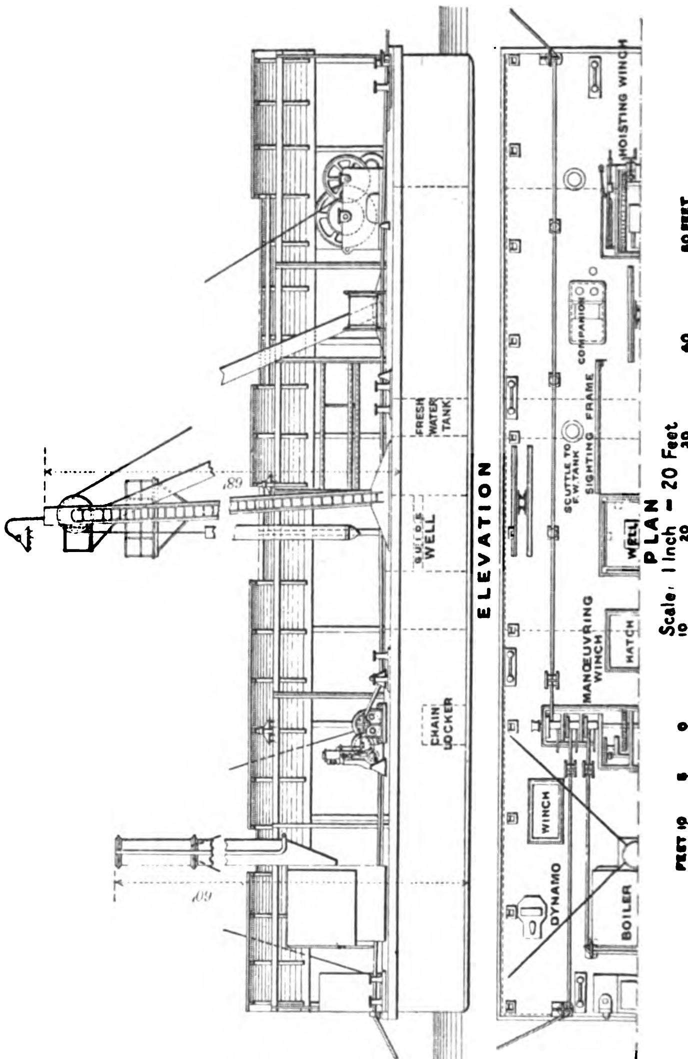
[1] Minutes of Proceedings Inst. C.E., vol. xcvii, p. 369; vol. cviii, p. 432.

At the centre of No. 1 barge there is a well through which the ram works; this machine cannot work nearer to any quay-face than one



Figs. 1.

half the beam, or 14 feet. In the second rock-breaker the ram works at one end of the barge, so that the rock can be broken close up to quay-faces; this barge, however, has the disadvantage of

considerable movement in the water while the machine is at work. The guide for the ram is fitted with powerful volute springs to lessen the lateral shock of the blows; the tension of these springs is adjusted by wedges. The boiler and machinery are on deck. The legs of the tripod are of a box section, are built of steel and are riveted to the deck; they are sufficiently high to allow of the point of the ram being raised level with the deck for examination or renewal of the point.

The rams are 40 feet and 50 feet long respectively; they are made of forged steel, turned and machined all over, and tapered to conform to the total stresses at each section; the maximum diameters are 19½ inches and 16¾ inches respectively, and the weight of each ram is 15 tons. The shorter the ram, the larger its diameter must be for any given weight, and, consequently, the better it is able to withstand the stresses due to the blows; to determine the length (in tidal waters) the required depth of water at low water is added to the rise of average spring-tides, and the ram should be about 5 feet longer than the sum. At Blyth the average rise of spring-tides is 14 feet 6 inches. When not in use, the ram is hoisted out of the water and slung with chains to the tripod.

The wire-rope attachment at the upper end of the ram consists of a couple of corrugated gluts 12 inches long, embracing the rope and let into a recess bored out of the head of the ram. Six tightly screwed set-bolts, 1¾ inch diameter, passing through the ram-head, cause the gluts to grip the rope. During the 8 months No. 1 rock-breaker has been at work, this attachment has failed only once, and that failure was caused by an inexperienced man. Great care should, however, be taken that the set-bolts are thoroughly tightened up, because, in certain circumstances, the consequence might be serious should the rope slip out. It is important to have a spare set of these bolts, for after being used several times, a "burr" or "rag" forms upon their ends when screwed up against the gluts, and it is then difficult to unscrew them, and in one or two cases they had to be drilled out. A satisfactory method to follow is to use the spare set-bolts each time a new wire rope is put on; the original set-bolts can be filed down at the ends, rescrewed if necessary, and kept ready for use.

The lower end of the ram has a tapered socket to receive the point, which resembles in shape an armour-piercing projectile. This point is of vital importance, and it is made of specially hardened steel, the composition of which varies according to the kind of rock to be broken. The hardness of the steel increases towards the centre, which has the effect of preserving the pointed shape as the point

wears—a very important feature in effective breaking up of the rock. The life of one of these points is about 1,000 working-hours. The point is secured to the ram by three set-screws, which are set into an annular recess in the spigot of the point; the heads of the set-screws are sunk flush with the face of the ram. Considerable difficulty was experienced in withdrawing the point from the socket in the ram, and improvement is required in this direction. On one occasion, hydraulic pressure, amounting to about 5 tons, was applied at the top of the spigot, and at the same time steel wedges were driven in between the point and the ram, yet it required a whole day to produce any movement of the point. The wedges tended to damage the bearing area of the ram upon the spigot. The hydraulic pressure was applied through a small hole leading into a recess bored out of the ram at the head of the socket. Heating the foot of the ram is sometimes effective in loosening the point, but this method is not altogether advisable. Surrounding the foot of the ram and let into it, is a hoop of specially hard steel, which strengthens that part of the ram against the bursting effect of the spigot, and, in addition, serves to resist the wear, and so protects the extreme end of the ram. With continuous working, the point, and 2 or 3 feet of the ram, become highly polished. For about 12 inches above the hoop the ram was found to have been hollowed out $\frac{3}{16}$ inch, after 8 months' working, by the abrasion of the rock.

The hoisting-winch is driven by a double-cylinder non-condensing engine, supplied with steam at about 100 lbs. per square inch pressure from an ordinary marine return-tube boiler, and suitably geared to a shaft upon which rides loosely a barrel 3 feet in diameter; the surface is spirally grooved to prevent the coils of wire rope from riding upon each other. A chilled steel centre, embraced by a steel spiral coil-clutch attached to the barrel, is keyed to the shaft. The coil-clutch is actuated by a system of levers, and is provided with a small spring to assist it in releasing its hold when put out of action. This spring can be adjusted to prevent any seizing of the coil. The coil-clutch suddenly snapped one Monday morning, immediately after the tightening force had been applied, possibly owing to a keen frost that had set in the night before. Since then, if the winch had been standing for any length of time during frosty weather, duck lamps were placed in the vicinity of the coil to warm it, before putting the winch into operation. The winch is provided with an ordinary brake. The exhaust steam is carried through a feed-water heater, and thence alongside the funnel. A feed-pump worked by the winch supplies the boiler through the feed-water heater. The manœuvring winch is driven by a double-cylinder engine, and has six independent

reversible chain-barrels, fitted with warping ends; it works all the necessary mooring-chains, and is operated by one man. For night-work, the rock-breaker is fitted with forty 16-candle-power glow-lamps in clusters, supplied with current from an engine and dynamo on the barge.

To operate the rock-breaker, the barge is first brought over the site, the surface of the rock having previously been dredged clean, and there it is securely moored in position by single fore and aft cables and side chains at each quarter—six chains in all. The ram is then gently lowered until the point rests upon the rock, and a gauge, painted on the ram, indicates to the hoisting winchman the required height of lift, generally about 8 feet. When lifted, steam is partially shut off to prevent the winch-engines racing, and the coil-clutch is released to drop the ram. The operation of raising and releasing the ram is continued until the rock is penetrated to the required depth. The barge is then moved to a spot 3 or 4 feet away, and the ram allowed to penetrate the rock to the same depth as before, after which it is moved another 3 or 4 feet, and so on.

Each new position of the ram must be fixed with great care, and this is effected by two sighting-poles on shore being kept in line with two sighting-rods on board. The space between adjacent spots penetrated by the ram in one direction is called the "pitch," while the spacing in a direction at right angles is called the "advance." The pitch and advance are always made equal. The pitch first adopted at Blyth was 3 feet, but was increased to 3 feet 6 inches, then to 4 feet, and ultimately to 4 feet 6 inches. This latter pitch is now maintained throughout. The rock removed consisted, for the greater part, of the calcareous sandstone commonly found in the coal measures, portions of which were almost as hard as granite. The beds of sandstone alternated with thin layers of shale and sometimes of coal. The dredging results of the various pitches were carefully watched, but the only perceptible difference between the 3-foot pitch and the 4-foot 6-inch pitch was that with the latter the pieces of broken rock were larger than with the former, and there was no practical difference in the rate of dredging. Theoretically, there ought to be a certain most economical pitch and advance, according to the degree of hardness of the rock to be broken, and it is worth while ascertaining this pitch by experiment, if the character of rock is fairly uniform over large areas; but where the rock is varied in character, it is advantageous, for practical reasons, to ascertain the best average pitch and advance and to maintain them throughout. The total penetration is generally 3 feet; with a

greater penetration there is risk of the ram occasionally sticking fast in the rock. With a fall of 8 feet, about four blows per minute can be delivered. The number of blows for a penetration of 3 feet varied from five to fifteen, according to the hardness of the rock, but for fairly hard sandstone eight blows may be taken as an average. The pieces of rock broken with a 4-foot 6-inch pitch average about $\frac{1}{4}$ cubic foot, but occasionally there were pieces weighing about 1 ton. The rock is generally so well broken up that it can be dredged fully 15 per cent. faster than blasted rock, and a uniform surface on the rock is obtained.

Experiments made with the rock-breaker on hard rock exposed at low water showed that the rock was completely pulverized on the spots where the ram fell, and, for about a foot around each hole made by the ram, the rock was broken into small pieces and forced up above the original surface; beyond this the rock was thoroughly fissured, and some of the pieces were forced up. The thorough breaking up of the rock is an advantage for dredging purposes, as compared with blasted rock. It frequently happens in blasting rock under water, when the strata are horizontal, that the rock surrounding the lower portion of the bore-hole containing the shot is completely shattered, but the upper parts are only fissured, and not dislodged—due probably, in part, to the overlying weight of water. The dredger has, consequently, considerable difficulty in breaking into this rock when commencing to dredge a new area—a difficulty which does not occur when the rock-breaker is used.

The rock-breaker was originally fitted with two sighting-frames, each having a vertical sliding bar, and allowing of a total advance of the barge of 13 feet 6 inches for each position of the poles on shore, but this advance was found to be insufficient owing to obstructions between the barge and the shore, and also to allow of spanning graving-dock entrances, etc. A sighting-frame was therefore erected along each side of the barge for nearly its full length, allowing of a total advance of about 80 feet before the poles on shore need be moved. At night time the poles on shore are indicated by lamps. The poles are placed alongside pegs previously put in position and are at right angles to a base-line, which is plotted upon a plan kept in the office, and upon which the progress of the rock-breaker is recorded day by day. A graduated measuring-wire, wound around a small drum on board, with one end fixed to the base-line, gives the position of the barge. Some difficulty was experienced in preserving the correct positions of the barge when

ships lay between it and the sighting-poles; this difficulty was, in some measure, overcome by maintaining the bearing of the base-line on a mariner's compass, and by careful manipulation of the manœuvring-chains.

The wire rope used at Blyth for lifting the ram is 5 inches in circumference and 167 feet long, and is composed of six strands surrounding a hemp core. An eye is spliced at one end for attaching to the drum. This wire rope is subject to severe usage, and consequently its life is short, so that it is one of the chief items in the cost of maintenance. Should the winchman apply the friction-clutch before the ram has struck the rock, the wire rope is subject to a severe pull, and a severe stress is put upon the winch itself; should he, however, be late in applying the clutch the wire rope will spin off the drum and kink at the head of the ram, and also close to the drum. With practice, men acquire considerable skill in operating the winch, but, even when the application of the clutch is correctly timed, a certain amount of slackening of the rope invariably occurs, which sometimes forms a kink at the head of the ram. There are two places where the wire rope tends to fail, one near to the ram-head where the kink occurs, and the other at the drum, due to friction. Considerable friction, and consequent wear of the rope, also takes place at the sheave, which is 3 feet in diameter, for at the moment the ram has struck the rock the rope is at a standstill, but the sheave continues to revolve by virtue of its kinetic energy; at Blyth, however, none of the wire ropes have had to be taken off on this account. To lessen the sharpness of the kink at the ram head the wire rope is laid with serving-wire for a distance of 15 feet from the ram-head attachment, and a later improvement is to worm the rope with $\frac{1}{4}$-inch soft iron wire before putting on the serving. There is great difficulty in getting wire rope of suitable quality, as it must be soft enough not to be affected by kinking, hard enough to resist friction, and have a sufficient margin of safety for working. Experiments are at present being made at Blyth with various kinds of wire rope from different makers, but up to the present the longest life of a wire rope has been 495 actual working-hours. At least two spare wire ropes are always kept on board ready for use.

In a harbour or waterway the shore fastenings for the mooring-chains of the barge are an important matter, and if ordinary single- or double-fluked anchors are laid down in a harbour-bottom they may be a source of danger to shipping. Based on the experience at Blyth the Author's opinion is, that the best system of land mooring for rock-breakers, where quays are concerned and where a large

amount of rock has to be removed, is to have chains attached permanently by a diver to the quay-face, as low down as possible, and of sufficient length to be brought up to near the top of the quay, where the ends are temporarily fastened. The chains are spaced at convenient intervals along the quay, and are easily brought into use by shackling them to the ends of the rock-breaker's chains. This affords a more expeditious and convenient system of mooring than that of a bridle-chain along the quay. The initial cost of laying these chains will be more than compensated for by the saving in labour, and by the time that the rock-breaker itself would probably otherwise be idle. These moorings can, moreover, be used by the dredgers.

The rock-breakers at Blyth work on double shift, and are manned by two crews, each consisting of four men:—the skipper, the hoisting winchman, the manœuvring winchman and the stoker. It has been found that seafaring men make the best skippers, but they must be active, intelligent, and of fair education. It is an advantage if the hoisting winchman is a fair mechanic, as he can then more readily understand the cause of, and possibly remedy, any trifling breakdown of the machinery. Each crew works a week on day-shift and a week on night-shift alternately, making eleven shifts, of 12 hours each, per fortnight per man. The following are the full-time wages paid to the crew, viz.:—

	£	s.	d.	
Skipper	2	4	0	per week.
Hoisting winchman	2	0	0	„ „
Manœuvring „	1	14	0	„ „
Stoker	1	14	0	„ „
Total wages	7	12	0	„ „

The coal-consumption averages 2 tons 9 cwt. per 24 working-hours. A large wooden tank carried on a barge is used to convey fresh water to the rock-breakers. The level of the bottom of this tank being above the top of the tank in the rock-breaker, no pumping is required. The consumption of water is about 17,000 gallons for a full working-week. Salt water could be used, but for many reasons it is less economical.

Weather is a factor much affecting the cost, and in this connection the Author has observed that the motion of the rock-breaker due to 18-inch waves causes the ram in falling to strike the guide, thereby essening the force of the blow, and necessitating a larger number of blows for a given penetration.

When rock has to be removed above low-water level in tidal

harbours, the time during which the rock-breaker can work is limited by the height of the rock and by the range of the tide, and it is an advantage if there is rock to be broken in deeper water close by. It is safer only to work on high rock with a rising tide, for then should the wire rope suddenly fail, or come out of its attachment, the flotation of the barge may be used to lift the ram, and when the latter is clear of the ground, the barge can be hauled into a safe position. Serious damage might ensue to the barge if the wire rope failed when working on high ground on an ebb tide.

A systematic method of recording the results of the rock-breaking is essential for economical working, and the Author therefore adopted a system of daily recording sheets, compiled from the returns, from which the quantity of rock broken per day is obtained. These sheets give the following information: the number of the "ordinate" (an ordinate is a line followed by the rock-breaker at right angles to the base-line), the pitch, the advance from the last ordinate, the distance of the ram from the base-line, the penetration of the rock for each series of blows, the number of blows for each position of the ram, etc. All delays and stoppages, with the reasons, are also recorded, together with the times of stopping and re-starting work. In this way, the progress of the work could be closely followed, and any laxity in the working of the rock-breaker immediately detected, as well as the stoppages arising from preventable causes.

It was ascertained at Blyth, by soundings taken both before the rock was broken, and after the dredging, that when the ram penetrated 3 feet the rock could be dredged for a depth of 2 feet 6 inches.

As rock-breaker No. 2 was only put into operation recently, the following particulars refer to rock-breaker No. 1.

The maximum quantity of rock broken in one week was 1,975 cubic yards. The total quantity broken over a period of 27 weeks, including holidays and other stoppages, was 24,535 cubic yards, giving 908 cubic yards as the weekly average.

During the period of 27 weeks 229 shifts were worked, each of 12 hours, and since eleven shifts constitute a full week, $\frac{24,535}{229} \times 11 = 1,177$ cubic yards, is the average for a full working-week.

The following is an analysis of the rock-breaker's working-time over the 27 weeks above referred to, derived from the daily record sheets:—

Delays (excluding holidays) due to—	Per Cent.
Shifting moorings to new positions, and picking up and shackling together mooring-chains broken by ships	9·12
Traffic	3·18
Repairs, including changing of wire ropes and ram-points	20·68
Weather and moving to new moorings and berthage at week-ends	5·75
Boiler-cleaning, etc.	6·54
Tide	1·28
Meals	7·75
Total delays	54·30
Actual time breaking rock	45·70
Total working-time	100·00

The total cost of breaking the rock is obtained as follows:—

Details of working costs for 27 weeks—	£	s.	d.	£	s.	d.
Wages of crew, towage, supervision and proportion of expense of water, and coal-conveyance	434	1	9			
Coal (net cost)	138	7	7			
Water [1] (net cost)	20	9	6			
Stores	17	8	10			
				610	7	8
Maintenance—						
Repairs, labour and material	74	0	9			
Boiler-cleaning	10	0	0			
Five wire ropes	73	13	10			
Clutch-coil and small springs	44	0	0			
Sliding disk	10	17	6			
Two ram-points	32	0	0			
				244	12	1
Total expenditure over a period of 27 weeks				854	19	9

Since the total quantity of rock broken in the 27 weeks was 24,535 cubic yards, the working-cost per cubic yard is—

$$\frac{£854\ 19s.\ 9d.}{24{,}535} = 8\cdot36d.$$

[1] Net cost of water = 1*s.* 2*d.* per 1,000 gallons. The cost of transport and delivery of water, namely, 1*s.* 10*d.* per 1,000 gallons, is included in the item of £434 1*s.* 9*d.*

The cost of the rock-breaker (including ram) was £6,800, whence—

		£
Interest on capital	at 4 per cent.	272
Depreciation	„ $2\frac{1}{2}$ „ „	170
Insurance	„ 2 „ „	136
	Total	578

or £300 for 27 weeks.

So that the amount per cubic yard is—

$$\frac{£300}{24{,}535} = 2 \cdot 94d.$$

Total cost of breaking rock (including interest, etc.)

$$= 8 \cdot 36 + 2 \cdot 94 = 11 \cdot 30d. \text{ per cubic yard.}$$

The $2\frac{1}{2}$ per cent. allowance for depreciation is in the Author's opinion ample, assuming that the rock-breaker is well maintained.

In estimating the probable cost of rock-breaking over a period of years, allowance must be made, of course, for periodical docking and painting, but the ram constitutes the heaviest item of maintenance, owing to the wear by abrasion of the bottom 2 or 3 feet. There is also the liability of the ram to fracture in the course of time, due to fatigue. Messrs. Lobnitz and Co. state, as the result of their general experience, that the total cost of repairs and renewals will not exceed that of all the other working-expenses put together, and the Author believes this to furnish a safe basis for an estimate. Hence:

For 27 weeks—	£	s.	d.
Average cost for wages, coal, stores, etc., as previously ascertained	610	7	8
The estimated allowance for cost of repairs and renewals (including periodical docking and painting), based on Messrs. Lobnitz and Co.'s estimate, can therefore be put at the maximum figure of .	610	7	8
Interest, depreciation, and insurance, as above .	300	0	0
Estimated total cost	1,520	15	4

Hence the estimated total cost of breaking rock, including interest, depreciation, etc., is

$$\frac{£1{,}520\ 15s.\ 4d.}{24{,}535} = 1s.\ 2 \cdot 9d. \text{ per cubic yard.}$$

The average cost of drilling and blasting sandstone rock at Blyth was 3*s*. per cubic yard. The drilling-craft consisted of a barge, upon

which was mounted a derrick and overhanging platform, an ordinary vertical boiler and a winch-engine. The drills, six in number, were worked by hand, assisted by ropes attached to the drill cross-heads, and led over sheaves at the top of the derrick to barrels upon a long shaft driven by the winch. The winch was kept continuously running, and the lifting and releasing of the drills were effected by alternately tightening and slackening two or three turns of the rope around each barrel. Bellite was the explosive used, and an average of about 488 cubic yards of rock per week were broken, the craft working night and day.

In comparing the removal of large quantities of rock by the rock-breaker and by blasting, the following are the chief points in favour of the rock-breaker, viz., (1) The cost is considerably less; (2) the rock is broken at a quicker rate; (3) the rock is broken to a more convenient size for dredging, so as to increase the rate of the latter operation by about 15 per cent.; (4) the rock can be broken at places where it would be injudicious to use explosives; (5) freedom from the danger incidental to the use of explosives.

The engineers to the Blyth Harbour Commissioners are Messrs. J. Watt Sandeman and Son, of Newcastle-upon-Tyne, and the Author is the Resident Engineer.

The Paper is accompanied by a tracing from which the Figures in the text have been prepared, and by two photographs.

(*Paper No. 3711.*)

"On the Cost of Power at Mines of the Witwatersrand, with Reference to a Proposed Supply from a Central Source."

By Henry James Shedlock Heather, B.A., M. Inst. C.E., and Anthony Maurice Robeson.

The suggested transmission of power on a large scale to the Rand from a generating station, either at the Victoria Falls or at some less distant coal-field, rendered it necessary for the Mechanical Engineering Department of Messrs. H. Eckstein & Co. to carry out careful tests to establish the accuracy of, and if necessary to amend, the monthly power returns sent in by certain of the mines under that firm's control. The number of horse-power-hours could thus be ascertained, and, since the expense of production was known, the present cost of the unit of work at each mine, and consequently the price which that mine could afford to pay to a supply-company, could be arrived at. This price would not by any means be the same for all the mines, because of the condition of the generating plant at each mine (regarded both from an absolute point of view, and in reference to the estimated life of the mine). The geographical position in respect of the coal-supply; the cost of any water required in addition to that derivable by pumping from the mine itself; the likelihood of any extensions in the use of power and consequently of plant, due for instance, to the increasing depths from which winding and pumping might have to be carried out, and the modifications in reduction processes such as the introduction of tube mills, also have a material influence on either the present or the future costs.

The inquiry was limited to "producing" mines, and of these, all that were situated at a greater distance than about 10 miles from the centre of Johannesburg were excluded. One mine, within the central district, was not dealt with because it would be probably worked out before any general power-distribution scheme could be

available. Seventeen mines were thus included in the investigation, representing a total annual use of about 160 million indicated horse-power-hours, equivalent to a constant power (reckoned on a 100 per cent. load-factor) of over 18,200 I.HP. The investigation was begun towards the end of 1905, and occupied the time of the Authors and of a number of assistants for about 6 months, but in addition many of the figures required were compiled by the staffs of the various mines. On one mine for example, about 30 men were employed for 30 consecutive hours in taking indicator-cards, electrical readings, speeds of revolution, etc.

The object of the investigation, viz., the determination of the price which the various mines could afford to pay for power purchased, did not require to take into consideration interest on the capital already expended. If the change from separate to centralized power-production were made, such a large amount of machinery would be thrown on the market as to flood it, hence the existing plant had to be considered as being of no value. For either system therefore, i.e., separate or centralized power-supply, interest on the existing plant would continue, and it was consequently unnecessary, in a comparison, to include it on either side. The future cost of running on the present system was accordingly regarded as including additional costs only from the time when a central-supply station could be expected to be at work. From this date boiler-renewals were allowed for during the life of each mine, as well as the cost of repairs and renewals in the mine-shops to maintain the steam-engines in their then state of efficiency. In the event of power being taken from a central source (whether the means of transmission were electricity or gas—and both of these methods had been suggested), it is obvious that the boiler-house charges would be eliminated, but the simple deduction of these costs from the total running-costs would not give a figure which, when divided by the number of indicated horse-power-hours, could be compared with the cost of 1 horse-power-hour when obtained from a central source. The two figures were not comparable owing to two facts. In the first place, if all the steam-plant were thrown out and replaced by either gas-engines or electric motors, it would not follow that the number of prime movers under the new system would be the same as under the old, since the old system is the growth of years and is, in most instances, capable of improvement by the omission of long shaftings, belt and rope transmissions. In the second place, the efficiency of the necessary transformations would not be identical in all cases, and the difference would be most noticeable in the case of electricity; for instance, the efficiency of

hoisting and air-compressing by means of three-phase motors varies considerably from that of the same work done by reciprocating engines; further, the power required for lighting would be used immediately in its electrical form instead of needing to be converted from mechanical to electrical power. These matters will be referred to more particularly in dealing with the various classes of operations that are involved in running gold-mines, such as those of the Witwatersrand.

An estimate had to be made of the engine-room expenses (including repairs), of the number of men on shift under the new system, and of the cost of repairs to electrical and other new machinery. In the case of electricity, data were available to form such an estimate, in the recorded costs of the considerable existing electrical plant in the mines.

Classification of the Operations of a typical Witwatersrand Mine.

(1) *Mine-Pumping.*—The pipe-columns are sometimes vertical and sometimes inclined, and either Cornish pumps, or air- or electrically-driven pumps are employed. In the few instances where water is removed by baling, the power used is dealt with under the heading of winding.

(2) *Winding* is sometimes either entirely vertical or entirely inclined. In other instances it is partly inclined and partly vertical, and the travelling skips either pass from the incline to the vertical and up to the surface by being pulled round the bend by the same engine and rope, or there is an underground tip at the junction of the two portions of a compound shaft, the rock being reloaded for the vertical journey. The skips may be in balance or unbalanced, and are used for hauling men and materials, such as ore, waste, drills, timber, and in some cases water. The hauling is generally effected by means of a drum or with Whiting winders. At the mines considered there were no conical drums at the time the measurements were taken, and only three flat rope (reel) hoists. Driving is effected by steam, compressed air, and electricity.

(3) *Air-Compressing.*—All the mines considered use air-compressors for running machine-drills and in many cases for underground hoists and pumps. All the compressors are of the reciprocating type and are steam-driven.

(4) *Crushing and Sorting.*—After arrival at the surface the ore is sorted out and is crushed, by means of stone-breakers, to a size suitable

for use in the stamp-mills. The sorting requires little power, the ore being carried on revolving tables, or on slowly running belts, and the waste rock is picked out by hand. The crusher-stations are usually steam-driven, either by their own, or by the stamp-mill engines, transmission being effected in the latter case by shafting, belts, or ropes. A few crusher-stations are run wholly or in part by electricity.

(5) *Stamp-Milling.*—The stamp-mills are in all cases steam-driven: the engine is always the largest on the property and works under the most constant load. The stamps themselves, which form the bulk of the load, show practically no variation in the load at any one mine and are kept running 24 hours per day and 7 days per week. On this engine a load-factor of over 90 per cent. can therefore be expected.

(6) *Raising of Tailings* for the purpose of enabling them to gravitate to the tube-mills (if in use, as they were in one case only at the period dealt with) and to the cyanide-treatment tanks is, in almost every case, effected by tailings-wheels, driven by the stamp-mill engines.

(7) *Grinding in Tube-Mills.*—The mills were driven, at the time considered, by the stamp-mill engines.

(8) *Cyanide Treatment.*—The pumps in the extractor-houses are driven by wire ropes from the stamp-mill engines, by separate engines or by electric motors. The extractor-houses contained also zinc-lathes, filter-presses, and often lime-mills, also return-water pumps for enabling the process-water for the stamp-mills to be used over again.

(9) *Tailings and other Haulages.*—The final process is the remova of the treated tailings which, owing to the general flatness of the country have to be transported to the dumps by means of trucks carried along by an endless wire-rope commonly driven by the stamp-mill engine. In addition to this haulage, there are generally other surface haulages conveying the rock from the shafts to the crusher-stations and from these again to the stamp-mills. These haulages are also mostly carried out by endless wire-ropes, though in some case conveyor-belts are used, as well as separate steam and electric locomotives.

(10) *Electric Load.*—Dynamos for the supply of electric light and power are generally driven at the older mines by the stamp-mill engines, but often have their own engines on the more recently developed properties.

(11) *Repair-Shops*, blowers for drill-sharpening, tools, etc., are ordinarily driven by separate engines or motors.

(12) *Power in Assay Offices* is required to drive grinders, samplers, etc., and is very small in amount.

(13) *Condenser-Pumps and Boiler-Feed Pumps, Economizers, etc.*—The horse-power-hours required for these purposes were not taken into consideration in dealing with the costs. Condensers are not to be regarded, when dealing with the cost of power, as an end, but as a means of reducing the cost by enabling a smaller quantity of steam to do the required work. The boiler-feed pumps and the economizers come under boiler-house charges, and are eliminated altogether when the question of purchasing power from a central station arises.

The foregoing list of operations includes all those ordinarily met with on every mine, but in some instances there were minor services which, though of small magnitude, had yet to be taken into consideration.

In determining the work done in the different processes strict accuracy was seldom obtainable, and approximate methods were of necessity often adopted. The investigation had to be carried out in the shortest possible time consistent with accuracy, and as an average figure for each mine had to be arrived at, data extending over as long a period as possible had to be obtained wherever they could be relied upon. Indicator-cards could not always be taken simultaneously in such numbers as would have been desirable, owing to the lack of the necessary instruments. The knowledge gained, however, from the investigations at a mine where circumstances allowed of a high degree of accuracy could often be used in checking the results of another mine where the measurements were more difficult to obtain, and on the whole the Authors have no hesitation in asserting that the results arrived at differ but little from the truth. The methods adopted in dealing with the various operations will be described as fully as possible without giving an unreasonable amount of detail.

Methods adopted in the Investigation.

(1) *Mine-Pumping.*—The height of lift and the length of pipe were accurately known in all cases from the mine-surveys. Where the pumping is done by Cornish pumps and steam-engines the daily and monthly numbers of revolutions of the latter were in almost all cases obtainable from the recorded readings of revolution-counters. A period of 6 months was usually taken, and the months selected were those that would give a fair average, taking into consideration that in the Transvaal there are, in every year, two very distinct seasons,

namely the dry and the wet. The dimensions of pump-plungers were of course accurately known. Indicator-cards taken periodically by the resident engineers were also available.

In the case of electrical pumps (which at the time of the investigation were driven by continuous current exclusively) the number of hours run had been recorded; owing to the nature of the work the amperes were constant and were known. In the cases of both electrically-driven and air-driven pumps there was no need to carry the investigations further than the dynamo-terminals or the compressor-cylinders, as the case might be, as in the event of power being taken from a central source the further transmission of power from these points to the water lifted would not be affected; that is to say, the air-driven pumps would not be changed, although the compressors might be driven by gas-engines or electric motors, and the electric pumps would be driven by existing dynamos for the reason given on p. 356. The power in these cases was therefore included in the indicated horse-power corresponding with the total outputs of dynamos or compressors respectively.

As, in the case of Cornish pumps, the useful work done could be more easily and accurately ascertained than the work developed in the steam-cylinders, a figure for the efficiency from steam to water was assumed and was checked by comparison with indicator-cards. This overall efficiency was put at 0·7 for pumps with vertical rods, and at 0·65 for those in which the rods were carried down an incline, to allow for the increased friction due to the pump-rods and the extra length of pipe. It should be mentioned that the dip is fairly uniform in all the mines and approximately 30°, except for a short distance from the outcrops.

(2) *Winding.*—The depths to every level and the angles of dip of inclined shafts were all accurately known. Records of the number of trips from every level and the nature of the load hoisted, ore, water, drills, men, etc., had been kept by each mine. The weights of the skips or cages and of the ropes, as well as those of the various loads, were easily obtained, and the speed of hoisting, when the acceleration period was completed and uniform motion had been attained, was determinable by measuring with a stop-watch the time taken for the drum, etc., to make a given number of revolutions, taken in conjunction with the known diameter of the drum. These data afforded a means of arriving at the useful work done. On the other hand, in the case of hoisting by steam, indicator-cards had been regularly taken and the full running-speeds were known; and from these particulars the rate of producing work in the steam-cylinders, when running at full speed, could be determined.

In almost all cases, however, the indicator-cards available had been taken at full speed only, and consequently the work done during acceleration was very difficult to evaluate. In fact, the use of this method, coupled with the running-time of each trip, yielded estimates of the amount of work done in hoisting which were, almost in every case, very largely in excess of any figure that could be regarded as approximately true. As already stated, the work done in the shaft in raising the load of ore, etc., and the cage and rope (when unbalanced) was therefore taken as a basis for an estimate of the work done in hoisting. Theoretically, if the moving load were allowed to come to rest under the influence of gravity just at the end of each trip, there would be nothing but friction to add to the foot-tons so obtained in order to arrive at the work done in the engine-cylinders, but it was recognized that in practice some of the energy imparted to the system was invariably dissipated by the use of the brakes, and that occasionally the brakes were applied too early or too hard, so that the load had to be again slightly accelerated. The theoretical work done in accelerating the whole load was therefore calculated, and in addition the moments of inertia of the winding-drums or sheaves, and of the headgear sheaves, tail-rope sheaves and tension-carriage sheaves where existing, had to be obtained to determine the energy stored in them. It was estimated that in the case of hoists, either simply vertical or simply inclined, 15 per cent. of this acceleration work was lost in braking, leaving 85 per cent. as being returned during the retardation process. In the case of compound shafts, where the same skip passes round the curve from an inclined into a vertical shaft, the hoisting-engine is slowed down at the time when either the rising or descending skip is on the curve. Unless both skips arrive at the curve at approximately the same time (as is only usually the case when hoisting from one particular level), slowing down and re-accelerating occurs twice in each trip in addition to the original accelerating. For each time that this slowing down and re-acceleration occurred, 10 per cent. of the work done in accelerating to the full speed was considered to be lost. To the work done in raising the total load was added 15 per cent. of the acceleration work and in the case of compound shafts a further addition of either 10 per cent. or 20 per cent., as the case might be, was made. To the total so obtained was added another 15 per cent. to represent shaft- and engine-friction and the final figure was taken as the indicated horse-power-hours used in hoisting.

It may be mentioned that before the whole of the investigations forming the subject of this Paper were concluded, four Little

continuous recording indicators (in which the operations both of taking an indicator-card and obtaining the area of the diagram are continuously carried out) were available. One of these was applied to each end of each cylinder of one of the flat-rope hoisting-engines, and readings were taken over one complete trip. The method above described for determining the indicated horse-power-hours used in hoisting is more difficult of application in the case of a flat-rope hoist than in any other, owing to the fact that after the engine has attained the constant speed fixed by its governor, the rising load is gaining, and the falling load is losing speed, because the effective diameter of the reels is continually increasing or decreasing in consequence of the changing number of the laps of the ropes. In spite of this increased difficulty, the indicated horse-power-hours for one trip, as calculated and as determined by the indicators, were in almost absolute agreement.

As in the case of pumping, the equivalent of the indicated horse-power-hours used in hoisting by electricity or by compressed air were adequately allowed for in considering the outputs of electric generators and air-compressors respectively.

(3) *Air-Compressing.*—In this case methods of computation totally different from those above described were employed. All the compressors were driven by reciprocating steam-engines. The particulars available were records of the daily number of revolutions, daily continuous charts recording air-pressures, and periodically-taken indicator-cards of both steam- and air-cylinders. These cards, however, had almost always been taken when the engines were running at full speed and against the maximum air-pressure, and therefore could not be used, in combination with the number of revolutions, to determine the indicated horse-power-hours, as the air-pressure was often (mainly owing to the air-load being at times greater than the compressors could properly take) below that at which the air safety-valves were set to blow off. A new determination of the average horse-power-hours per revolution was accordingly necessary. For this purpose the continuous air-pressure charts from each compressor on every mine were collected. Generally speaking, the load on any particular compressor is practically constant for 5 days out of the 7 in every week. On Sundays no machine-drilling is allowed, and the load is consequently very much lighter on the whole mine; but it does not follow it will be lighter for any particular compressor, as the whole work may be put on to one engine instead of being divided between two or three. Very often on Saturdays also no afternoon shift was run underground, and the same reduction might hold good. The recording charts were there-

fore assorted into different days, and a few typical charts were selected for each day of the week from every compressor, and from these selected charts a mean air-pressure was determined. Bristol recorders, in which the pressure is registered on a revolving circular disk of paper, and the arm carrying the pen is pivoted at a fixed point, were principally used. The lines representing time and pressure are consequently all circular, so that the ordinary method of determining the mean pressure from the area enclosed by the pressure-line does not give accurate results. The true mean pressure was found by plotting out in a few instances the pressure-curve on the record on to squared paper, from which a coefficient was found which gave quite sufficiently accurate results for practical purposes, by multiplying by the planimetered area on the circular card. This method is obviously approximate; it was only due to the very close similarity between the curves for all compressors that it was safe to use it at all. No other method, however, allowing of the work being carried through in time to render the results valuable for the object in view presented itself, and it was therefore adopted. Arrangements were then made to allow of the exclusive use of each engine for some hours on a Sunday. The air-receiver safety-valve was set to blow off at the average pressure as obtained from the Bristol charts, and the engine was run at the speed corresponding with the average as found by dividing the total counter-numbers, over the period considered, by the running-time. Indicator-cards were simultaneously taken at both ends of both steam-cylinders, and from these a constant representing the indicated horse-power hours corresponding with one revolution of the crank-shaft was obtained, and it only remained to multiply the total number of revolutions in any period by this constant in order to arrive at the indicated horse-power-hours for the period. Thirty-two compressors were thus dealt with, and the results showed that the values previously adopted at the mines were very near the truth, though usually somewhat on the high side.

(4) *Crushing and Sorting.*—Usually the power was obtained from the stamp-mill engine through shafting and belting. In one case an electric motor was used alone, in another case an electric motor did part of the work whilst a separate steam-engine did the rest, and in four instances separate steam-engines drove the crusher-stations. In all of these cases the work done was easily estimated. The hours of running had always been recorded, and indicator-cards and switch-board-readings had been taken in sufficient numbers to enable a fair average of the power to be arrived at. The determination was not quite so simple when the transmission of power was effected by mechanical means from the stamp-mill engine. As above mentioned

this engine is in all cases the largest on the property, and the work done by it generally represents about half the total work done at any mine. The horse-power-hours required by the crusher-station are only one-tenth to one-twentieth of the total of the stamp-mill engine. The running time of the crusher-station load is considerably less than that of the greater part of the rest of the work done by the stamp-mill engine, because milling goes on for 7 days a week, whereas ore-winning is not carried on on Sundays. There is an absence of any ore-storage capacity on the surface except in the mill-bins, and the sorting out of waste rock can be carried on with greater ease by daylight. On the whole, crushing- and sorting-stations do not, as a rule, run more than about half the total time that the stamps are at work. The ratio of the actual power taken by the crusher-station to the total mill-engine power is therefore about double that of the horse-power-hours used for the crusher-stations and the total mill-engine services. The power-ratio is thus between one-fifth and one-tenth, and this ratio could usually be still further raised by temporarily taking off some portion of the mill-engine load. The indicated horse-power due to the crusher-station could, therefore, be determined with a reasonable degree of accuracy, by taking indicator-cards of the mill-engine—generally relieved of some of its other load—with and without the crusher-station on, subtracting the result of the one set of cards from that of the other, and making an allowance for a proportion of the engine-friction. Confirmation could often be obtained from cases in which the load of the crusher-station was known to be of a similar magnitude, but was carried by a separate engine or by an electric motor. The power thus arrived at, multiplied by the recorded running-time, gave the horse-power-hours for the crusher-station.

(5) *Stamp-Milling.*—The work done in driving the stamps was capable of very close determination. Records of every minute that any stamp is not running are accurately kept, and consequently the number of stamp-hours during any period are immediately deducible, whence the average number of stamps running can be obtained. All the stamps in any one mill are ordinarily of the same average weight, are lifted the same height, and the same number of times per minute; due allowance was made for one case where this uniformity did not exist. The procedure was to relieve the stamp-mill engine of all its load except that due to the stamps and to the tailings-wheel. This wheel cannot be stopped whilst the stamps are running, for it is the only means of carrying the tailings to the cyanide treatment. The mill was run with as nearly as possible the

average number of stamps running during any period under investigation, and since the stamps are usually made up in batteries of five the number of stamps running was the multiple of five nearest to the average number. A series of indicator-cards were taken, after which an extra battery or two was added and cards were again taken: then the same process was gone through with one or two batteries taken off. Thus the amount of power required for each extra stamp when about an average number were running was obtained, and consequently a very close estimate was reached of the power used by a battery containing the average theoretical number of stamps. Results obtained from different but similar mills were of course compared, and there was a satisfactory agreement.

(6) *Raising of Tailings.*—The tailings-wheel was, as already mentioned, of necessity running whenever stamps were at work. The power taken by it was therefore included in the previous determination. This procedure was not only necessary but is also correct, as the work done by the tailings-wheel varies directly as the number of stamps running.

(7) *Grinding in Tube-Mills.*—At the time of carrying out these tests there was only one tube-mill at work in the seventeen properties under consideration. It was rope-driven by the stamp-mill engine, and the power taken by it was ascertained by inference from indicator-cards of an engine, the only load on which was a similar tube-mill. Confirmation was obtained by taking indicator-cards from the mill-engine with the tube-mill on and off.

(8) *Cyanide Treatment.*—The extractor-house load consists almost entirely of pumping, and is somewhat variable in amount. In about half the total number of instances driving was effected either by separate engines or by electric motors, and then the number of horse-power-hours was, as in the case of separately-driven crusher-stations, quite simply determined. If, however, the stamp-mill engine was the source of power and the transmission was effected by wire rope, indicator-cards taken with and without the extractor-house running had to be depended upon. The load was not a large portion of the total engine load, though as a rule larger than that due to crusher-stations. Nevertheless, fairly consistent results were obtained, and in view that more or less similar extractor-houses, driven by their own engines, were available for comparison, the Authors have no reason to doubt the close accuracy of the results.

(9) *Tailings and other Haulages.*—The determination from the stamp-mill engine indicator-cards of power for the surface haulages, which at some of the mines were four and even five in number, and most frequently driven by the mill-engine, was not likely to be very

satisfactory. Such of these haulages as were more or less continuously running generally took very little power, say 20 HP. each, out of a mill-engine load of 600 to 800 HP., whereas those using more power, such as for lifting the ore from the bottom of the crusher-station to the top of the mill-bins, were only in operation for such a short period at each trip that it was difficult to take the cards at the right moment. A comparison with the few cases using an electric-motor drive showed that the most accurate method was to multiply the total weight lifted by the height, and then to make an estimate of the efficiency of the process. These estimates were probably close approximations, and, as they dealt only with small amounts of power, any error would only slightly affect the total figure. Where conveyor-belts took the place of rope-haulages, electric motors were the driving-machines and then switchboard-readings gave reliable results.

(10) *Electric Load.*—As regards power electrically transmitted, switchboard-readings, combined with the recorded number of hours run, were all that was required to get an accurate figure on which to base a calculation for the equivalent number of indicated horse-power-hours. The lighting load was almost equally easily dealt with, and the greater part of it, namely, the lighting of mill, extractor-houses, etc., was an all-night load, and all lights were put on and taken off practically simultaneously. In crusher-stations, headgears, etc., the running-time had been booked so that the number of hours of lighting was known; underground lighting went on all the time the lighting-dynamos were running. A small portion remained for which only a rough estimate could be made, viz., that absorbed in lighting married and single quarters, recreation-rooms, etc. Any error introduced into this estimate could have only a very small effect on the figure arrived at for the whole. As a matter of fact, on a mine the ratio between the number of lamp-hours used in lighting the quarters and the number got by multiplying the total lamps by the number of dark hours shows a remarkable constancy, when the figures are taken over a fairly long period, so as to eliminate the effect of Saturdays and Sundays. This is partly owing to the uniformity of occupation of the users of the light, and partly on account of the practical absence of twilight at Johannesburg. In estimating the indicated horse-power-hours due to electric loads the losses in the transmission of power from the steam-engines to the dynamos were duly allowed for.

(11) *Repair-Shops.*—These shops were in all cases driven either by electric motors or by their own engines. In the former case the power used was got from switchboard-readings, in the latter

from indicator-cards. The time of running was always recorded sufficiently closely.

(12) *Power in Assay-Offices.*—The small demands for power made by the assay-offices were almost always supplied by electricity, air being used in only one or two cases. The total was so small as to be quite negligible in comparison with the other figures.

In two instances in the seventeen mines considered, power for some of the services was obtained from the Rand Central Electric Works, and was paid for by meter. In each case the total so purchased was small as compared with that produced on the property. The readings of the meters were accepted as correct and the results were converted into equivalent indicated horse-power-hours in the usual way. In the Appendix, Table I, column F gives the final results for the seventeen mines considered in respect of the number of indicated horse-power-hours required per annum, and the cost, based on figures got from the various actual periods to which power-calculations apply, are also given in Table I. Column B of this Table, "Amortisation for future boiler-house requirements," is obtained from the estimated life of each mine, combined with an estimate of the number and cost of the new boilers, etc., that would have to be put in during that life. For the reason given on p. 344, neither the interest on the capital outlay, nor the depreciation of existing plant, is included in columns B and C. The rest of the Table explains itself.

It will be noticed that the cost (columns G and H) shows a considerable variation, the highest (Mine No. XI) being almost double the lowest (Mine No. VIII). In most cases, except those showing the lowest figures, the costs were being reduced even while the tests were being carried on, and at the time of writing, a year later, there was a considerable all-round improvement. It is expected that in time the steam running-costs at all of the mines will be reduced very nearly to the figures at which they stand for the properties showing the best present economy, such differences as will ultimately remain being the result of geographical position, an element which of course cannot be eliminated.

Comparison with Supply from a Central Source.

The first method considered of supplying energy to each mine from a central source was the transmission of gas from a colliery to drive gas-engines. In order to estimate the cost, it was first necessary to determine the gas equivalent of the steam indicated horse-power-hour for each operation on the mine. The gas-engine, being a reciprocating machine similar to the ordinary steam-engine, could replace the

latter, and would do the same work in the same way, with the exception of hoisting-work, however. It was quite clear, in view of the troublesome starting of gas-engines, that they could not be directly applied to hoisting-operations, and the indirect method of driving a dynamo by a gas-engine continuously running, combined with a reversible motor for driving the hoist itself, was studied. The net power for the hoisting work (i.e. the power obtained as explained on p. 349, before adding the 15 per cent. for shaft- and engine-friction) was taken, and 10 per cent. was added to cover shaft- and gear-friction, and the result was converted into gas indicated horse-power-hours, assuming efficiencies of 90 per cent. for the motor, 98 per cent. for the electric leads, 93 per cent. for the generator, and 80 per cent. for the gas-engine. For all other operations the figures for gas-engine indicated horse-power-hours were obtained from those for steam by altering them inversely in the ratio of the assumed efficiencies of the two types of engines. The ratio decided upon was 85 to 80, that is to say, one sixteenth was added to all steam-engine figures (except in the case of hoisting) to get those for the gas-engines.

The cost of running a gas-engine equipment was obtained by means exactly similar to those used in the case of an electrical equipment as described later. It was soon evident that the mine costs of running gas-engines were so high that only an impossibly low figure could be paid for the gas, and the calculations were therefore abandoned after being carried out in respect of four mines only.

In an electric-supply scheme a three-phase alternating current was for most purposes the only method that needed to be considered for motor-driving. Even in the unlikely event of power being transmitted from the Victoria Falls, or over any other long distance, by continuous current, distribution would certainly have been arranged for on a three-phase system. This did not imply that every continuous-current motor would be replaced by a three-phase motor. In many instances there were complete continuous-current installations, and, as it happened, all the mine-wiring had just been either entirely renewed, or brought up to date, in order to satisfy the requirements of the fire-insurance companies, who had become stricter in their regulations owing to the occurrence of several severe fires during the previous 2 or 3 years. Especially, therefore, in cases where the life of the mine was short, it might easily be more economical to put down one three-phase motor to drive the existing continuous-current generators, rather than to change the whole system to a three-phase equipment. In some mines, however, the existing electrical service

was unimportant, and it was found that it was usually cheaper to adopt three-phase distribution throughout.

Three-phase current being accordingly decided upon for all purposes for which electricity had not hitherto been used, the method of its application presented no difficulties except in the case of hoisting. The simplicity of the induction motor, its power of starting against load, and its nearly constant speed under constant periodicity, indicated it as an almost ideal driver for all purposes where approximate regularity was desirable. On the other hand, its low efficiency during acceleration was a great drawback to its use for such intermittent work as hoisting. The only alternative, however, to the direct employment of an induction motor for this purpose was its indirect application by making it drive a continuous-current generator kept constantly running, and using the latter to drive a continuous-current motor on the Ilgner system, in which the massive fly-wheel averages the load on the generator by storing up energy when the load is light and returning it during the momentary slowing down due to starting work under a heavy load. Two extra transformations are involved, both of which reduce the efficiency, but, when the distance hauled is short, the work done during the acceleration period is large in comparison with that done during the rest of each trip, and then the loss due to the double transformation and to keeping the heavy fly-wheel running whilst the hoist-motor is standing still, may not amount to so much as the loss due to inefficiency of an induction motor when running below its proper speed. At the mines considered, however, the haulages are usually somewhat long, and in most instances are becoming longer owing to upper and earlier worked portions of the ore-deposits becoming exhausted. Moreover, many of the shafts are inclined, and owing to the necessarily lower speed of hauling, the ratio between the time occupied in acceleration and in running at uniform speed is reduced, so that the simpler method of applying an induction motor to drive the hoist-drum directly was found to be preferable to the use of the Ilgner system. Since the periodicity adopted for very large distribution-system mainly used for power purposes would certainly be low, no difficulty in designing motors to run slowly enough to be coupled directly to drum-shafts would arise, so that no question of reduction-gearing need enter into consideration.

These points being settled, it remained to determine what amount of power taken in the form of electricity would do the same work as the horse-power-hours developed in the steam-cylinders of the existing engines.

Dealing with the matter from a general point of view, the amount of power to be paid for would be measured, at the entry of the high-pressure current to the step-down transformers. From this point to the motor-pulley an efficiency of 0·864 could be expected made up of the factors 0·98 for the transformers, 0·98 for the low-tension leads, and 0·9 for the motors. This efficiency is practically identical with that of the average steam-engine reckoned from the steam in the cylinders to the crank-shaft, and consequently wherever the means for converting the work at the motor-pulley and at the crank-shaft pulley into useful work were identical, or equivalent, the figure found for steam horse-power-hours could be adopted without alteration for the horse-power-hours to be paid for in the electrical form. When the means of conversion were different an alteration in the figure would be required.

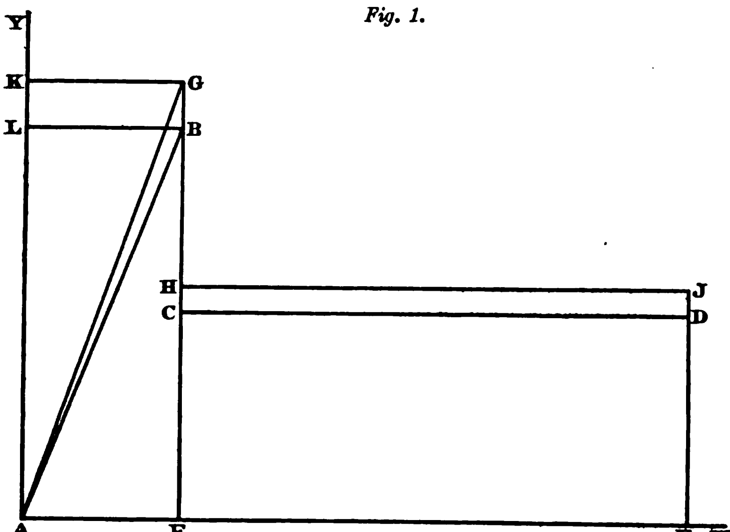
The various operations were accordingly dealt with as follows:—

(1) *Mine-Pumping.*—The efficiency of an electrically-driven pump might be taken as the same as that of a Cornish pump, and consequently, bearing in mind the preceding paragraph, the horse-power-hours used in pumping electrically could be taken as being the same as those for a steam-driven pump. Existing electrically-driven and air-driven pumps would be accounted for as explained on p. 348 in considering the output of existing dynamos and compressors respectively.

(2) *Winding.*—The modification required to convert the figures for steam-winding into their practical electrical equivalent turned out to be much greater than that for other services. A three-phase induction motor, together with its starting-switch, absorbs as much power, when exerting any particular torque at a speed below that which would be full speed for that torque, as if it were running at full speed, the difference between the useful work done plus the losses in the motor itself and the input into the motor being absorbed in the starting-switch and converted into heat. Thus in *Fig. 1* (in which time is plotted along AX and power along AY), the area A B C D E represents the useful work done in one trip by a double-drum hoist in which the rope is in complete balance (i.e., in which a tail-rope of equal weight to the main ropes is used), the portion A B F represents the work done during acceleration, and F C D E the work done during uniform motion. A continuous-current motor driving this hoist (assuming for simplicity a motor-efficiency of 0·9 at all speeds and loads, which might be approximately the case in a continuous-current motor) would require to be supplied with an amount of energy represented by the area A G H J E, in which B F is 0·9 of G F, and C F is 0·9 of H F. A three-phase motor doing the

same work, and of the same efficiency so far as the motor itself is concerned, would, however, require to be supplied with an amount of energy represented by the area A K G H J E, the energy represented by the area of the triangle A K G being absorbed in the starting-resistance. The area A K G is equal to the area A L B multiplied by the ratio of A K to A L, or to the area A B F multiplied by the same ratio, that is to say, the work represented by A K G is equal to the work done during the acceleration period (made up of the work of acceleration plus the actual foot-tons lifted during the period divided by the figure for the motor-efficiency). In determining the amount of energy, therefore, that would have to be paid for in

Fig. 1.



the electrical form the process adopted was to double the foot-pounds of work done during the acceleration period, and divide the total by the estimated full-load efficiency of the motor.

(3) *Air-Compressors.*—A rather considerable modification had to be made in dealing with air-compressors. The efficiency from the steam-cylinder to the air-cylinder (when the two cylinders are in tandem) is higher than that from the cylinder to the crank-shaft in a steam-engine, because a great portion of the power is transmitted directly from the steam-cylinder through the piston-rod to the air-cylinder, and does not have to pass into the crank-shaft at all. It was assumed that, in general, the efficiency from steam to air was 0·9; this figure being known to be exceeded in some cases.

The steam indicated horse-power-hours being known, multiplication by 0·9 gave the air horse-power-hours required. In applying an electric motor to drive a compressor the motor would drive on to the crank-shaft, and it was assumed this would be done through ropes so as to use a fairly high-speed motor. The air horse-power-hours divided by 0·85 were taken as representing the crank-shaft horse-power-hours, and further division by 0·95 for the rope efficiency, 0·9 for the motor, 0·98 for the leads and 0·98 for the transformer, converted the crank-shaft horse-power-hours to horse-power-hours supplied to the transformers, and consequently gave the amount to be purchased. This process, arithmetically simplified, is equivalent to a multiplication of the steam indicated horse-power-hours by 1·29.

For all other services, with the exception of the lighting and power supplied by existing installations, the conclusion on p. 357 holds good, and the electric horse-power-hours to be purchased are equal to the steam horse-power-hours when the engine was directly connected to its work, but in other cases the steam horse-power-hours had to be multiplied by the combined efficiencies of any drives that would be eliminated by the change.

As explained on p. 357, a motor would be put in to drive existing generators in some instances, but in others existing generators with their driving-engines would be entirely done away with. In this latter case the lighting would be done by alternating current of a low periodicity, but a periodicity of, say, 25 cycles per second is not objectionable for the lighting of engine-rooms, etc., and few people can notice the fluctuations in the light even when reading or writing. With a motor-driven generator system the electrical horse-power-hours would be the same as the steam indicated horse-power-hours previously taken; but if the electric supply is used directly, the electric horse-power-hours would be less than this figure in the ratio of the combined efficiency of the steam-engine generator and leads to switchboard to that of the transformer to the switchboard. A considerable reduction often resulted. In order to ascertain the cost of running such an electrical equipment at a mine, the necessary capacity of each motor was fixed, and an estimate was prepared for each complete installation.

The interest on the capital outlay was reckoned at 5 per cent. per annum together with the amortisation over the estimated life of the mine, subsequent to the date at which the new system could be expected to start work. The result of the calculations are shown in Column A of Table II.

Column B shows estimated running costs. In order to arrive at these, each engine-room with the new equipment was taken by itself, and a schedule was drawn up of the number of men (white and coloured) required on each shift, with their rates of pay. The cost per shift under this heading did not usually differ to any great extent from the present figure. To fix probable repair-shop expenses, the present expenses on engine-room repairs were taken and reduced by an amount estimated as representing that portion due to condenser-repairs. The fact that, in order to provide emergency-crews for breakdown work it was necessary to keep workshop-charges above a certain minimum figure, was borne in mind, and therefore in some cases engine-room costs were not reduced to the extent that some advocates of electricity might think permissible. Expenses of supervision were not included, as they had not been taken into account in obtaining the present costs, and it was expected that a resident engineer's salary would not be reduced by the removal of boiler-house supervision from his duties.

Column C is the sum of Columns A and B, and represents the total annual mine costs.

Column D is the difference between corresponding figures in Column E of Table I and Column C of Table II, and accordingly represents the annual price that each mine could afford to pay for purchased power, so as to show neither loss nor gain when compared with present costs of work.

The figures in Column D, when divided by those in Column E, Table II, show what each mine could afford to pay for the horse-power-hour without making any gain by the change. The result is given in Column F, and as it is obvious that to make the change justifiable some saving must be effected, the mines would not be prepared to pay quite so much as the figures given.

Column G is merely the annual price of the horse-power corresponding to the hourly figure given in Column F.

It is desirable to point out that these mines are distinct concerns owned by different bodies of shareholders; it is therefore not practicable to strike an average of the various prices that could be paid for power and assume that its purchase at anything below this average would be a good business proposition for all of them. It cannot even be assumed that any of the mines which could, on present figures, afford to pay the highest price would be justified in purchasing at a slightly lower figure than that given, because almost every mine has a reasonable hope of being able to reduce its power-costs, at any rate approximately, to the lowest shown in Table I.

From the figures here given it seems probable that, in the case of "producing" mines fully equipped with sufficient machinery to run them to the end of their lives, with the exception of boilers requiring renewal, it will be difficult for any company depending only on selling electric power to make reasonable profits. The case is quite different when "developing" mines not yet fully equipped are being dealt with.

The main drawbacks to purely electrical supply lie in the low efficiencies of hoisting and air-compressing, when carried out electrically. One or both of these drawbacks are removed by the suggestion of one of the Authors, that a central power-station should be arranged to distribute power for two or possibly three services only; the three-service system would include (1) air for hoisting at a pressure of about 160 lbs. per square inch to suit existing winding-engines, known as the Cummings Dense-Air System and fully described by Mr. H. C. Behr, M. Inst. C.E., in a Paper read at a meeting of the Mechanical Engineers Association of the Witwatersrand, 28th May, 1904; (2) air, at about 80 lbs. pressure for the rock-drills, and (3) electricity for all other work. On the two-service system, air for drills at 80 lbs. per square inch would be supplied, and other work, including hoisting, would be done by electricity.

Figures corresponding with those now given for a purely electrical supply were worked out for both these systems, and it may be stated that the three-service system shows a very pronounced economy over that in which distribution is carried out by electricity alone.

The Paper is accompanied by one diagram, from which the Figure in the text has been prepared.

[APPENDIX.

APPENDIX.

TABLE I.—PRESENT STEAM-EQUIPMENT.

Mine Number.	A	B	C	D	E	F	G	H
	Boiler-Room Costs.	Amortisation for Future Boiler Requirements.	Engine-Room Costs (without Interest or Depreciation).	Extraneous Power Charges.	Total of A, B, C and D.	Indicated Horse-Power-Hours Per Annum.	Cost of I.HP. exclusive of Interest and Depreciation.	
							Per Hour.	Per Annum.
	£	£	£	£	£		d.	£ s. d.
I	17,968	1,107	6,915	..	25,990	7,174,100	0·8694	31 14 8
II	22,857	1,330	10,830	..	35,017	12,221,300	0·6877	25 2 0
III	29,035	1,645	11,372	..	42,052	11,828,200	0·8532	31 2 10
IV	20,585	1,272	9,212	3,899	34,968	9,416,000	0·8913	32 10 7
V	8,169	389	4,424	..	12,982	4,143,500	0·7518	27 8 9
VI	14,648	1,554	8,431	..	24,633	4,898,300	1·2069	44 1 2
VII	23,120	1,309	11,472	..	35,901	9,455,500	0·9113	33 5 3
VIII	19,507	Nil	8,500	..	28,007	10,096,200	0·6658	24 6 0
IX	31,656	1,177	8,873	..	41,706	9,913,800	1·0096	36 17 0
X	23,181	1,602	10,269	..	35,052	9,933,300	0·8269	30 3 7
XI	23,745	1,329	12,501	..	37,575	7,290,900	1·2369	45 3 1
XII	19,234	1,086	8,399	..	28,719	8,220,800	0·8384	30 12 0
XIII	32,969	4,246	10,176	..	47,391	12,907,400	0·8812	32 3 4
XIV	9,664	1,637	5,547	..	16,848	3,427,400	1·1797	43 1 2
XV	15,624	Nil	6,851	8,103	30,578	8,913,900	0·8232	30 1 0
XVI	49,551	1,697	15,246	..	66,494	18,574,900	0·8592	31 7 2
XVII	26,111	1,468	9,339	..	36,918	12,175,700	0·7277	26 11 3
	387,624	22,848	158,357	12,002	580,831	160,591,200		

TABLE II.—PROPOSED ELECTRICAL EQUIPMENT.

Mine Number.	A	B	C	D	E	F	G
	Interest at 5 Per Cent. on Capital Outlay and Amortization Over Life of Mine.	Estimated Annual Running Costs.	Total Annual Mine Costs A + B.	Difference between Total Costs by Steam (Col. E, Table I), and Mine Costs for Electricity.	Horse-Power-Hours to be Purchased Per Annum.	Maximum Price Payable. Per Horse-Power-Hour.	Maximum Price Payable. Per Horse-Power-Year.
	£	£	£	£		d.	£ s. d.
I	1,385	6,197	7,582	18,408	7,798,980	0·5665	20 13 7
II	2,843	10,103	12,946	22,071	13,122,250	0·4018	13 13 4
III	2,449	11,007	13,456	28,594	13,053,710	0·5257	19 3 9
IV	1,921	8,787	10,708	24,260	10,609,400	0·5487	20 0 7
V	1,223	4,145	5,368	7,614	4,270,700	0·4278	15 12 6
VI	2,163	7,662	9,825	14,808	5,055,250	0·7030	25 13 2
VII	1,324	10,525	11,849	24,052	10,508,630	0·5492	20 0 11
VIII	2,976	7,811	10,787	17,220	10,193,600	0·4054	14 15 11
IX	3,630	8,078	11,708	29,998	10,576,820	0·6807	24 16 11
X	2,406	9,118	11,524	23,528	10,804,400	0·5226	19 1 6
XI	2,972	10,042	13,014	24,561	7,524,150	0·7834	28 11 10
XII	2,249	7,616	9,865	18,854	8,806,520	0·5140	18 15 3
XIII	5,626	9,178	14,804	32,587	13,631,410	0·5737	20 18 10
XIV	1,703	4,309	6,012	10,836	3,554,390	0·7316	26 14 1
XV	6,233	6,471	12,704	17,874	9,382,170	0·4572	16 13 9
XVI	2,324	13,650	15,974	40,520	19,285,650	0·6287	22 18 11
XVII	1,999	7,877	9,876	27,042	13,644,260	0·4792	17 9 10

(*Paper No. 3677.*)

"The Use of Steel in the Construction of Large Water Service-Tanks."

By CHARLES WALTER SMITH, M. Inst. C.E.

STEEL has been adopted extensively in the construction of large service-tanks by the Sydney Board of Water Supply and Sewerage, the body controlling the water and sewerage works of that city and its suburbs.

The configuration of Sydney, and of the surrounding country, necessitates the employment of many service-tanks to ensure uniform and satisfactory water-service to the consumers. Already twenty-four tanks, of various types, have been provided, and more are in contemplation. During the year 1905–6, the volume of water consumed in Sydney and its suburbs was upwards of 8,000 million gallons, and of this volume, 5,000 million gallons were raised by pumping, either directly to those tanks or to the reservoirs supplying them.

Open service-tanks cannot be advocated in densely populated districts, where atmospheric impurities must abound; but in the suburbs to which, in this case, their employment has been restricted, the water is remote from any risks of serious contamination, and the use of such tanks appears to be free from objection. The tanks are, moreover, built within spacious reserves, having well-kept lawns planted with ornamental shrubs, and they are set back from public roads, and are thus greatly protected from the dust resulting from traffic. Whilst the high temperature and strong sunlight of the Australian climate are most favourable to the growth of algæ in open reservoirs, the high temperature is also favourable to the growth of polyzoa, crenothrix, and other objectionable forms of life, when sunlight and air are excluded from the water; and in the Author's opinion, the odours imparted to water by decaying polyzoa are far more objectionable than are those arising from the presence of the comparatively small quantities of algæ, etc., which grow in surface waters stored for a short time in tanks open to air and light. When the situation is wisely selected, and the water is not stored for any extended period,

it is evident that open reservoirs are far preferable to underground tanks when used in connection with surface waters.

Within the reticulated area six open steel tanks (Appendix, Table I) have been constructed; two of these have each a capacity of 1,500,000 gallons, and the others of 1,000,000 gallons each. The first three of these, constructed under Mr. C. W. Darley's direction, by the Public Works Department, have been briefly described[1] by him. The remaining three, modified in a few details of design, were built by the Board of Water Supply and Sewerage, under the direction of Mr. J. M. Smail, M. Inst. C.E., Engineer-in-Chief to the Board, and under the supervision of the Author. *Figs. 1* illustrate one of them, the Beecroft tank, just completed, which may be taken as fairly representative. The tanks are cylindrical in form, and rest on a concrete bottom, the floor being but a few feet below ground-level. Excellent foundations were obtained at very shallow depths in the Wianamatta shale, the rock overlying the Hawkesbury sandstone. This form of tank was suggested to the designers by the necessity for securing as much head as possible at the sites selected, and by the obvious saving of excavation in connection with the inlet and outlet works.

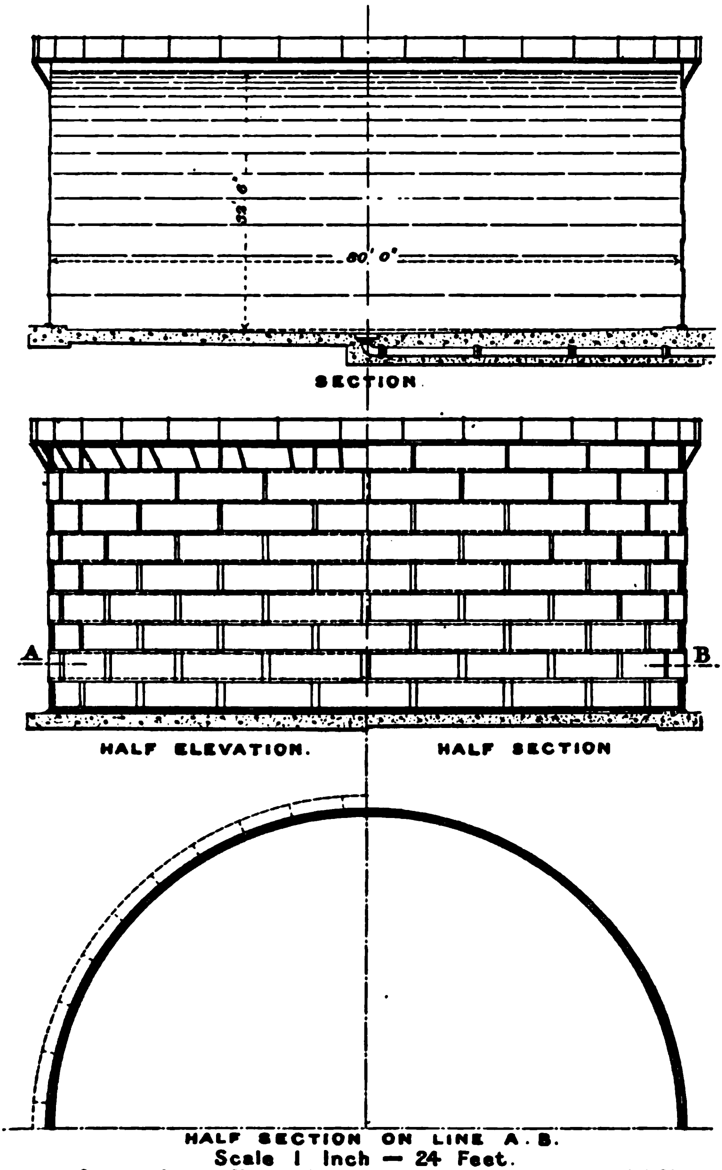
Excavation having been carried down to the required depth, the bed was left evenly and truly dressed, after which the floor of the tank, composed of Portland-cement concrete (4 parts bluestone, 1½-inch gauge; 2 parts sand; and 1 part cement) was put in, and was laid in two well-rammed layers of 9 inches each. The outer ring of the concrete was thickened by 3 inches, to form a foundation for the shell of the tank, and in it were imbedded, in cement mortar, eighty cast-iron stops, or shoes, which carry the cast-iron base-plates. There is a groove in the base-plate in which the steel shell of the tank stands. The base-plates were cast in lengths of about 6 feet 3 inches; each length had a projection at one end, and a recess at the other, planed and made to fit closely, so that when joined up these plates formed a true circle of the required radius. The seating of the shell-plates, as well as the under side of the base-plates, were planed truly parallel to the bottom surface of the groove, and every care was taken to secure an even horizontal bearing for the cylinder. The whole of the foundation work was very accurately laid out and checked during its progress, with a well-designed and correctly adjusted trammel.

The internal dimensions of the tank are: diameter, 80 feet, height, 33 feet 9⅛ inches; and the depth of water is 32 feet 6 inches.

[1] C. W. Darley, "Notes on the Use, Construction, and Cost of Service Reservoirs in New South Wales," Journal and Proceedings of the Royal Society of N.S.W., vol. xxv (1891), p. 147.

The capacity of the tank is therefore upwards of 1,000,000 gallons.

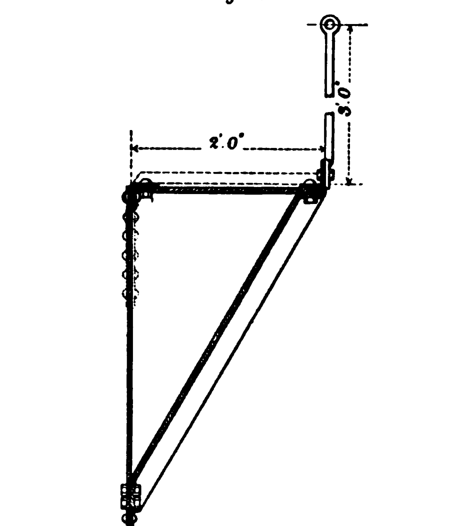
Figs. 1.



The shell of the cylinder consists of nine tiers, or rings of

plates, each 4 feet wide (with the exception of the top one which is 3 feet 6 inches), and about 12 feet 6 inches in length, so that there are twenty plates to each ring. The plates, cover-plates, and angles were all rolled to the required radius, and therefore, when riveted up, the form was truly circular. The edges of all plates were planed, and to a bevel where caulking was required. The stiffening strips are attached by countersunk rivets to the bottom, and to each side of the lowest ring of plates, and were also planed on their bottom edges, to ensure an even bearing, in combination with the ring-plate, on the bottom of the base-plate groove in which they rest. All the

Fig. 2.



DETAIL AT TOP OF TANK.
Scale ½ Inch — 1 Foot.

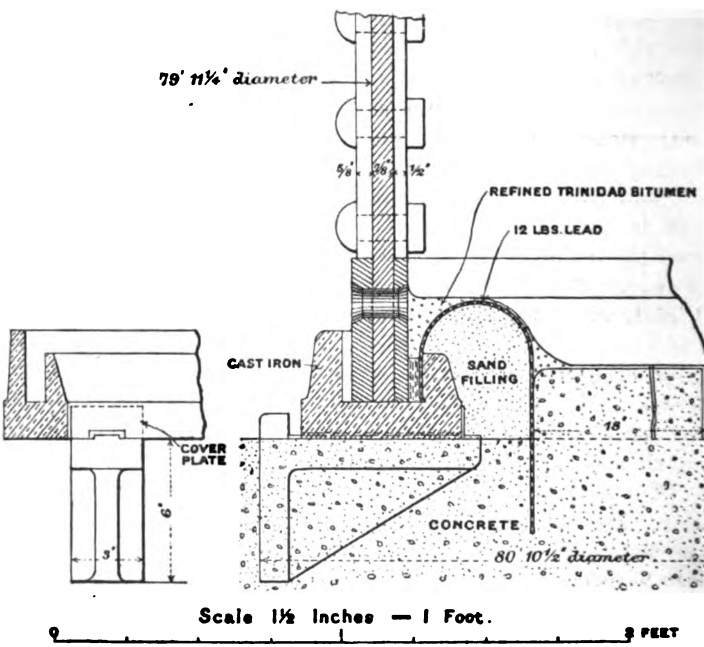
horizontal seams were lap-jointed and single riveted, but the vertical seams were butt-jointed with inner and outer cover-plates, and were double riveted. All the holes in the plates, stiffening-strips, straps, and angles, were drilled, and no drifting was necessary, the work having been done to template. As will be seen from *Fig. 2*, the top edge of the tank-shell was stiffened by means of an angle-bar 3 inches by 3 inches by $\frac{3}{8}$ inch. The thicknesses of the plates and cover-plates, the laps for each tier, and the pitches and diameter of rivets, are given in the Appendix, Table II. The quality of the material supplied more than satisfied the specified requirements. The plates and rivets used in the cylinder were of best mild steel

required to withstand an ultimate tensile stress of 28 tons per square inch of original section with an elongation of not less than 20 per cent. of the tested length (10-inch test-piece). For tests of this steel, see Appendix, Table III. All the riveting was done with a Tweddell hydraulic riveter, and all the caulking with a pneumatic caulker.

Wrought-iron ladders are fixed both inside and outside of the tank, and a gallery, bracketed to the top tier of plates, was provided for inspection purposes. To facilitate cleaning and painting operations, a manhole and cover was provided in the bottom tier. Much consideration was given to the subject of making a satisfactory joint between the concrete floor and the steel shell of the tank. This joint must not only be watertight, but must also allow the shell to move under the forces of expansion and contraction due to temperature, or under wind-pressure. Since the mean of observations extending over 46 years shows that the range of temperature in Sydney and its environs is from 35·9° F. to 108·5° F. in the shade, and from 24° F. (on the grass) to 173·3° F. in the sun, it will be seen that an empty tank will be subjected to very appreciable disturbances from change of temperature. All these requirements have been fulfilled by the adoption of a form of lead-joint, which the Author believes to be somewhat uncommon, and of which a full description may therefore be interesting. The interior connection between the steelwork and the floor of the tank was made by means of a sheet-lead ring (*Fig. 3*); one side of the sheet was let down into the groove of the base-plate in which the shell rests, and the other side was let into a recess originally left in the concrete floor, and ultimately filled with cement mortar. The sheet-lead used was milled to a weight of 14 lbs. per square foot; the pieces were cut across the sheet, and each measured 7 feet 9 inches by 1 foot 8 inches. A well-finished hardwood "horse," made to the exact cross-sectional outline (given in *Fig. 3*) and sweep of the lead ring, and about 9 feet long, was used for dressing the lead into shape. The ends of each piece of lead were carefully scarfed, smudged, cleaned, and tinned. It was first intended to place each piece in position separately, and wipe the joints in place; but the imprudence of doing this soon became apparent, and it was decided to wipe six lengths together to form a section before placing in position; these lengths were, of course, set out to the correct radius. The holes in the sheet-lead, through which the sand to fill the ring was eventually to be introduced, were then cut out, and the section was lifted into its place by the aid of ropes, kept in position by toggles inside the hollow ring.

Owing to the narrowness of the groove between the shell of the tank and the inner side of the bed-plate, into which the lead had to be caulked, a good deal of difficulty was experienced in making a reliable joint at the junction of the lead sections. The difficulty was, however, overcome by carefully tinning the scarfed edges. The bed-plate was covered with paper where the joints had to be made in order to keep the iron from robbing the lead of the heat obtained by means of powerful blow-lamps, and the heating was continued until a stick of wiping solder, applied to the tinned and heated surface of the lead,

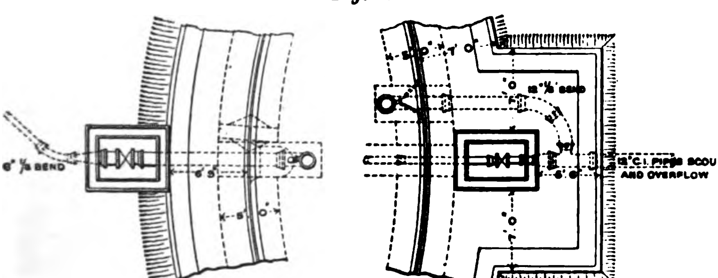
Fig. 3.



melted. When this was accomplished, small hardwood stops were slipped into the caulking-groove on each side of the joint, and the space between them was filled with solder, which was caulked immediately it had set. The remainder of the joint was then at once wiped without difficulty. So soon as all the sections were thus jointed, three rings of specially milled strip lead were caulked into the groove, and then the remaining space was run in with hot lead, which was caulked so soon as set. Cement mortar, 1 to 1, was then run in all along the inside of the groove left in the concrete floor,

until the mortar was flush with the level of the floor outside the lead ring, by means of the holes in the sheet-lead ring before mentioned, and through funnels attached to short lengths of rubber hose. When this cement mortar was thoroughly set, the hollow lead ring was filled with clean sand to prevent collapse when under water-pressure, and this sand was carefully rammed through the holes in the ring. The edges of the holes were then scarfed, smudged, cleaned, and tinned, and lead lids, made to an exact fit, were cleaned and tinned and wiped on to the holes. In order to give further support to the lead ring as a whole, a ring of concrete 3 inches high was laid adjacent thereto, and the small space left between the two rings was filled with Trinidad asphalt, which was also run over the remaining portion of the lead ring, adjacent to the tank-shell, as shown in *Fig. 3*. The space outside of the tank, between the shell and the base-plate,

Fig. 4.



DETAILS OF INLET PIPES SCOUR & OVERFLOW.

Scale 1 Inch = 16 Feet

FEET 10 5 0 10 20 30 FEET

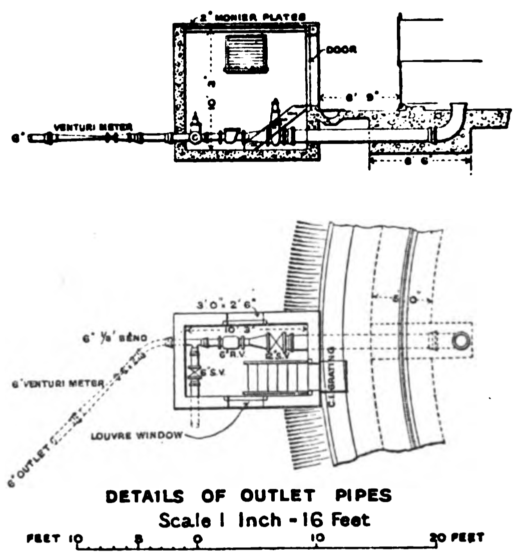
was filled with rust-joint cement, composed of 200 parts of cast-iron borings, 2 parts sal ammoniac, and 1 part flowers of sulphur, made into a paste with water, and well caulked.

The floor of the tank and all other exposed concrete work was rendered in cement. The mortar was composed of 1 part Portland cement, and 1½ part clean river sand, laid on in two coats of ⅜ inch thick each, troweled to a uniform surface, and then rubbed smooth by means of iron floats. Before being painted, the whole of the steel and ironwork was thoroughly scraped and cleaned with steel wire brushes, so as to remove all bloom and rust. Inside work was painted with four coats of red-lead and boiled linseed-oil, and the lead and the oil (both tested as to purity) were twice passed through a paint-mill immediately before use, so as to ensure thorough mixture, because the use of turpentine, or driers of any

kind, was not permitted. The outside work was painted with good lead-and-oil paint, the last finishing coat being of an approved stone colour.

The inlet- and outlet-pipes connecting the inside of the tank to the valve-chambers (*Figs. 4* and *5*), as well as the valves, are of a sufficient diameter to meet any future requirements. The floor slopes to the centre of the tank, and the scour is taken from that point. The overflow is connected outside the tank, to the same discharge-pipe as the scour. The water passes out of the tank into the delivery-

Figs. 5.



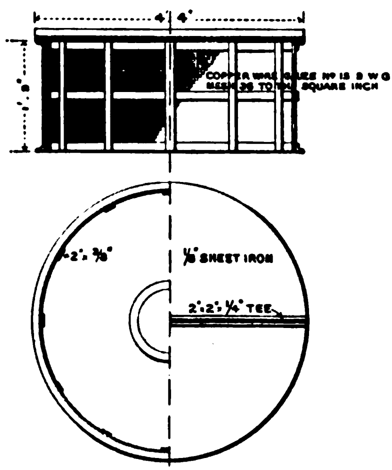
DETAILS OF OUTLET PIPES
Scale 1 Inch - 16 Feet

main through a circular strainer (*Fig. 6*) framed in wrought-iron with a sheet-iron top. The side through which the water flows is covered with copper wire (15 B.W.G.) netting of 36 meshes to the square inch. The output is measured either by a Venturi meter, or by a Fullway inferential-meter of the Board's standard pattern. The height of water in the tank is indicated by a small mercurial gauge, fixed either at the tank or at the adjacent residence of the caretaker (usually the turncock of the district).

When a tank, as in the case of that under notice, is situated at a considerable distance from the pumping-main, and is filled by gravitation from a reservoir at a superior elevation, the intake is controlled by a balanced ball-valve of the Glenfield type. The ball controlling the intake is fixed at the top of the tank, where it is protected from

wave-action by a steel shield. When a tank is filled by direct pumping, as is usually the case, the level of water is recorded in the pumping-station by an electrical indicator, registering every 3 inches of rise or fall. The cost of these open steel tanks certainly bears very favourable comparison with that of other types. The last three erected, each of a capacity of 1,000,000 gallons, cost on the average £4 6s. 6d. per 1,000 gallons, but that of the larger tanks referred to was considerably less. Particulars of cost of the last tank built are given in the Appendix, Table IV. Three of these tanks have been in use for more than 16 years, and although owing to exigencies of service the insides of the cylinders were not re-

Fig. 6.



DETAIL OF STRAINER FOR OUTLET.
Scale 1/8 Inch - 1 Foot
FOOT 1 0 1 2 3 4 5 FEET

painted for 8 or 9 years, the plates were only slightly pitted, and not to the extent that might have been expected, in view of the fact that the Sydney water is extremely soft, and attacks iron readily.

The exterior surfaces of plates are unaffected by corrosion and have a satisfactory appearance. From the foregoing it may be expected that, under favourable conditions of maintenance, the life of these tanks will be long. All the tanks are now cleaned out every year, and are repainted when necessary. Before repainting the inside plates, they are thoroughly cleaned by sand-blast.

The Paper is accompanied by an Appendix and by two drawings, from which the Figures in the text have been prepared.

[APPENDIX.

APPENDIX.

TABLE I.—PARTICULARS OF TANKS CONSTRUCTED.

Name of Tank.	Contents in Gallons (about).	Height of Steel Cylinder.	Diameter.	Thickness of Plates.								
				First Tier.	Second Tier.	Third Tier.	Fourth Tier.	Fifth Tier.	Sixth Tier.	Seventh Tier.	Eighth Tier.	Ninth Tier.
		Ft. In.	Feet.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
Chatswood, No. 1	1,500,000	34 1	100	1	1	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{5}{16}$
Chatswood, No. 2	1,500,000	34 1	100	1	1	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{5}{16}$
Ryde Hill	1,000,000	23 $8\frac{1}{2}$	100	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	..	..	..
Penshurst	1,000,000	34 1	80	1	1	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{5}{16}$
Wahroonga	1,000,000	26 $8\frac{3}{8}$	90	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{16}$	..	..
Beecroft	1,000,000	33 $7\frac{5}{8}$	80	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{3}{4}$	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{5}{16}$

TABLE II.—THICKNESSES OF PLATES, LAPS, PITCHES, &c.

Tier of Plates.	Thickness of Plate.	Lap at Bottom of Plate.	Lap at Top of Plate.	Rivets, Bottom Lap.		Rivets, Top Lap.		Butt or Cover-Plates.	Rivets in Cover-Plates.	
				Size.	Pitch.	Size.	Pitch.		Size.	Pitch.
	Inch.	Inches.	Inches.	Inch.	Inches.	Inch.	Inches.	Inches.	Inch.	Inches.
1	$\frac{7}{8}$	base 6	$3\frac{5}{8}$	$1\frac{1}{4}$	$4\frac{1}{8}$	$1\frac{1}{8}$	4	$12\frac{1}{4}\times\frac{1}{2}$ $12\frac{1}{4}\times\frac{5}{8}$	$1\frac{1}{8}$	$4\frac{3}{8}$
2	$\frac{13}{16}$	$3\frac{5}{8}$	$3\frac{5}{8}$	$1\frac{1}{8}$	4	$1\frac{1}{8}$	4	$12\frac{1}{4}\times\frac{1}{2}$ $12\frac{1}{4}\times\frac{5}{8}$	$1\frac{1}{8}$	$4\frac{1}{2}$
3	$\frac{3}{4}$	$3\frac{5}{8}$	$3\frac{1}{4}$	$1\frac{1}{8}$	4	1	$3\frac{5}{8}$	$11\times\frac{3}{8}$ $11\times\frac{5}{8}$	1	$4\frac{1}{8}$
4	$\frac{11}{16}$	$3\frac{1}{4}$	$2\frac{7}{8}$	1	$3\frac{5}{8}$	$\frac{7}{8}$	$3\frac{1}{8}$	$9\frac{3}{4}\times\frac{3}{8}$ $9\frac{3}{4}\times\frac{1}{2}$	$\frac{7}{8}$	$3\frac{3}{8}$
5	$\frac{5}{8}$	$2\frac{7}{8}$	$2\frac{7}{8}$	$\frac{7}{8}$	$3\frac{1}{8}$	$\frac{7}{8}$	$3\frac{1}{8}$	$9\frac{3}{4}\times\frac{3}{8}$ $9\frac{3}{4}\times\frac{1}{2}$	$\frac{7}{8}$	$3\frac{3}{4}$
6	$\frac{1}{2}$	$2\frac{7}{8}$	$2\frac{1}{2}$	$\frac{7}{8}$	$3\frac{1}{8}$	$\frac{3}{4}$	$2\frac{3}{4}$	$8\frac{1}{2}\times\frac{1}{4}$ $8\frac{1}{2}\times\frac{3}{8}$	$\frac{3}{4}$	$3\frac{1}{2}$
7	$\frac{3}{8}$	$2\frac{1}{2}$	2	$\frac{3}{4}$	$2\frac{3}{4}$	$\frac{5}{8}$	$2\frac{1}{4}$	$7\frac{1}{4}\times\frac{1}{4}$ $7\frac{1}{4}\times\frac{5}{16}$	$\frac{5}{8}$	3
8	$\frac{5}{16}$	2	$1\frac{5}{8}$	$\frac{5}{8}$	$2\frac{1}{4}$	$\frac{1}{2}$	$1\frac{3}{4}$	$6\times\frac{3}{16}$ $6\times\frac{1}{4}$	$\frac{1}{2}$	$2\frac{3}{8}$
9	$\frac{5}{16}$	$1\frac{5}{8}$	angle 3×3	$\frac{1}{2}$	$1\frac{3}{4}$	$\frac{5}{8}$	6	$6\times\frac{3}{16}$ $6\times\frac{1}{4}$	$\frac{1}{2}$	$2\frac{3}{8}$

TABLE III.—TENSILE TESTS OF STEEL USED IN THE TANKS.[1]

Test No.	Description.	Original Dimensions.			Limit of Elasticity in Tons per Sq. In.	Ultimate Stress in Tons per Sq. In.	Ratio of Limit to Ultimate.	Reduction of Area Per Cent.	Elongation Per Cent. on 10 Inches.	Remarks.
		Breadth.	Thickness.	Area.						
		Inch.	Inch.	Sq. In.						Plates.
1	Mild	1·505	0·78	1·174	15·1	29·8	0·56	53·4	26·0	$\frac{11}{16}$-in.
2	Steel	1·52	0·49	0·745	17·9	29·1	0·62	52·1	28·0	$\frac{1}{2}$ „
3	Plate	1·51	0·35	0·528	17·9	29·9	0·60	46·6	25·5	$\frac{3}{8}$ „

[1] Abstracted from the tests made at the University of Sydney, 19 March, 1906.

TABLE IV.—PARTICULARS OF COST OF AN OPEN STEEL WATER SERVICE-TANK OF A CAPACITY OF 1,000,000 GALLONS, AND OTHER WORKS IN CONJUNCTION THEREWITH.

Description.	Unit.	Quantity.	Schedule Rate. £	s.	d.	Amount. £	s.	d.
Clearing site	Item	..	15	0	0	15	0	0
Fencing around reserve, including gates, complete	1 yard	372	0	4	6	83	14	0
Excavation and earthwork	Cub. yd.	1,000	0	1	6	75	0	0
Concrete	,, ,,	395	1	15	0	691	5	0
Rendering in cement	Sq. yard	887	0	2	6	110	17	6
Cast-iron stops and base-plates, fixed	Cwt.	130	0	15	0	97	10	0
Steel-plates and rivets, fixed	Tons	114	16	10	0	1,881	0	0
Wrought iron-work, fixed	Cwt.	15	1	5	0	18	15	0
Laying and jointing 12-inch pipes	1 yard	58	0	2	0	5	16	0
Laying and jointing 6-inch pipes	,, ,,	115	0	1	6	8	12	6
Strainer for outlet-pipe	Item	..	..			12	0	0
Shield for ball-cock controlling intake	,,	..	..			3	0	0
Hardwood in deck of gallery	100 feet	Sup. 6	1	5	0	7	10	0
Valve-chambers	..	..	..			40	0	0
Lead-ring joint, complete, including inside and outside joints and asphalt	1 yard	84	1	11	0	130	4	0
Painting, four coats inside, three coats outside	..	..	..			213	15	0
Turfing slopes	Sq. yard	90	0	1	3	5	12	6
Drainage, etc.	Item	..	..			20	8	6
			Total			£3,420	0	0
The above items represent work done by contract at 4·75 per cent. above schedule rates, above set forth. 4·75 per cent. on £3,420						162	9	0
Cast-iron pipes and specials, stop-, reflux-, and balance ball-valves, lead, etc., used in connection with inlet- and outlet-works within reserve						196	11	0
Gun-metal Fullway inferential-meter on 6-inch outlet-pipe, complete						102	0	0
Supervision, freight on last two items, and sundries						269	0	0
Total cost						£4,150	0	0

OBITUARY.

SIR BENJAMIN BAKER, K.C.B., K.C.M.G., D.Sc., LL.D., M.A.I., F.R.S., was born at Keyford, Frome, Somerset, on the 31st March, 1840, and died suddenly, from heart-failure, on the 19th May, 1907. His family were descendants of British settlers in Ireland, from whom have sprung many men eminent in science, industry, and the public service. He was apprenticed to Messrs. Price and Fox of the Neath Abbey Ironworks at the age of 16, and remained with them until 1860. During the next 2 years he was engaged, under Mr. William Wilson, on works in connection with the Victoria Station and the Grosvenor Road railway-bridge, then recently opened. In 1862 Mr. Baker joined the staff of the late Sir John Fowler, Past-President Inst. C.E., with whom he remained associated until the death of the latter in 1898, rising from the position of junior assistant to that of partner. When Mr. Baker entered the office, Sir John Fowler was engaged on the construction of the Metropolitan and St. John's Wood Railways; and in 1869 he appointed Mr. Baker Chief Assistant Engineer on the construction of the District Railway from Westminster to the City, a work involving unusual difficulties. Before receiving this appointment Mr. Baker had established his reputation as an authority on both the theory and practice of engineering, having published important and original Papers dealing with Strength of Beams, Bridge Construction, Urban Railways and other subjects. In these Papers was displayed that remarkable combination of practical knowledge with scientific method which marked all Sir Benjamin Baker's work. In his career private study was the only possible means of supplementing practical knowledge gained during apprenticeship and service as an assistant: but hearty support and sympathy were always given by Sir Benjamin Baker to movements for improvement in engineering education; and the absolute necessity

for thorough practical training was equally enforced by him. This union of scientific and practical knowledge continued to be illustrated and successfully applied by Sir Benjamin Baker in dealing with problems of the greatest difficulty. In this respect the engineering profession owes much to his influence and example. It has been well said that he was one of the first to bridge the gulf which had long separated theory from practice in engineering. He gained the respect of those whose devotion to scientific methods made them liable to under-estimate the value of accumulated experience: while his practical knowledge, breadth of view, and dispassionate advocacy commanded the confidence of engineers of the older school, who were inclined to distrust the application of mathematical and scientific processes to works of construction.

During his long period of association with Sir John Fowler, Sir Benjamin Baker was concerned with works of great importance and variety. Urban railways naturally engaged much of his attention: the principles of their construction and working were already laid down in Papers published in 1874. His work on the District Railway in 1869 has been mentioned: Sir Benjamin Baker and Sir John Fowler were consulting engineers for the earliest "tube" railway (the City and South London), Mr. Greathead being the engineer: Sir Benjamin Baker was, with Messrs. B. Mott and D. Hay, engineer for all subsequent extensions of that line, as also for the Central London Railway, and jointly with Mr. Galbraith (after Mr. Greathead's death) for the Baker Street and Waterloo Railway. He acted as Consulting Engineer for similar works abroad, including the Hudson River Tunnel. As an assistant to Sir John Fowler, Sir Benjamin Baker began that connection with great engineering works in Egypt which lasted until his death. One of the earliest schemes on which he was engaged (about 35 years ago) was for the construction of a combined irrigation- and ship-canal between Alexandria and Cairo, which, however, was not executed. His final visit to Egypt was made early in 1907. During that visit he personally examined the valley of the Nile between Assuan and Khartum in order to ascertain the possibility or otherwise of erecting another dam instead of raising the dam at Assuan: he dealt with the latter problem, and was consulted in regard to the construction of bridges crossing the Nile near Khartum and at Cairo. In the modern development of Egypt Sir Benjamin Baker played a great part. His connection with the British Colonies and Dependencies was long and distinguished, and was recognized officially by the bestowal of the K.C.M.G. In conjunction with Sir John Fowler he acted as

Consulting Engineer to the New South Wales Government, and for many years advised in matters of railway construction. He was Consulting Engineer to the Public Works Department of the Cape Colony.

For many years before his death Sir Benjamin Baker was in partnership with Mr. A. C. Hurtzig. Upon the retirement of the late Sir William Shelford he became a partner with Mr. F. Shelford, and advised in the design and construction of important railways and engineering works in West Africa, Cyprus and elsewhere, acting as joint Consulting Engineer to the Crown Agents for the Colonies and other authorities. Amongst recent works for which Sir Benjamin Baker was responsible, or in which he acted as Consulting Engineer, may be mentioned the Avonmouth Docks and the Hull Joint Dock (in both cases being associated with Sir John Wolfe Barry, and Mr. C. A. Brereton, as well as Mr. Hurtzig), the Rosslare and Waterford Railway, the widening of the Buccleuch Dock Entrance, and the construction of the Walney Bridge at Barrow-in-Furness. At the time of his death he was acting as Consulting Engineer to several important railways.

Outside his own practice Sir Benjamin Baker attained an eminent position as a Consulting Engineer, to whom professional colleagues at home and abroad turned with confidence when they had to face conditions of unusual difficulty, or needed advice in the design of works of an unprecedented nature. Captain Eads corresponded with him in connection with the design of the St. Louis bridge across the Mississippi. When Cleopatra's Needle was to be transported from Alexandria to this country (in 1878), Mr. John Dixon, who had undertaken the work, consulted him as to the design of the vessel which was to convey the obelisk. In later years more striking instances occurred of the confidence felt in his opinion and advice by fellow engineers. Sir Benjamin Baker never failed to answer the appeal of those who sought his aid in circumstances of difficulty; and rendered valuable assistance even though (as was ordinarily the case) he had to bear simultaneously immense responsibilities in the execution of works which had been originated and designed by himself.

A very large number of engineers, many of whom now hold important positions, received their training under Sir Benjamin Baker, who maintained an active interest in the careers of his old pupils and assistants; being always ready to give them friendly assistance when they encountered difficulties in their work, or sought his advice.

His long service as a Civil Member of the Ordnance Committee

must also be mentioned. Sir Benjamin Baker was appointed to succeed Mr. Barlow in that position, and became the colleague of the late Sir Frederick Bramwell in 1890. On the death of the latter, in 1903, Sir Benjamin Baker became Senior Civil Member of the Ordnance Committee, Mr. Mallock being appointed as his colleague. During his life and since his death there has been ample recognition of the valuable services which he rendered. In the selection of the best materials for gun-construction; in the conduct of experiments to determine causes of failure and the means of avoiding their recurrence; in the design of guns and gun-mountings, and other important branches of the work of the Ordnance Committee, Sir Benjamin Baker took a prominent part. Again, in connection with the recent difficulty as to possible interference with the work of the Observatory at Greenwich in consequence of the construction of an electric generating-station in the neighbourhood, Sir Benjamin Baker was called upon to serve as a member of a Special Committee appointed to deal with the subject, and to make recommendations. His influence is clearly to be traced in the Report, which has commanded the acquiescence of all concerned. From the first he took an active part in the work of the Engineering Standards Committee, and was Chairman of the Sectional Committee on Bridges and Building Construction.

The great variety and the magnitude of the engineering works for which Sir Benjamin Baker was primarily responsible are indicated to some extent by the number of Papers contributed by him or by his assistants or resident engineers to the Proceedings. A list of those of which he was himself the Author is appended to this notice. No comment thereon is necessary. His name, however, will always remain most closely associated in the public mind with two of these works, namely, the Forth Bridge and the Assuan Dam. The Forth Bridge undoubtedly owes its inception in its present form to Sir Benjamin Baker, although he was at the time of the design a partner with the late Sir John Fowler, and was always desirous of acknowledging the valuable assistance which Sir John Fowler had rendered both in the design and in the construction of that grand structure. Like all great men, Sir Benjamin Baker was ever ready to recognize and acknowledge his indebtedness to those who worked with or under him; and to Sir William Arrol and others who did much to realize his design for the Forth Bridge, or to overcome the enormous difficulties that occurred in its erection, full honour was done in recording its history. But behind it all stands the original and daring conception, based upon scientific principles, and worked out with the greatest care.

Again, as regards the Nile Dam, while recognizing the great services rendered by Sir William Garstin, Sir William Willcocks, the late Mr. W. J. Wilson, Mr. A. L. Webb, Mr. M. Fitzmaurice and other engineers, it is only just to give first place to the work done and the responsibility assumed by Sir Benjamin Baker. Upon him as Consulting Engineer rested the final responsibility for advising as to the increased height to which it has been decided to carry the dam. Lord Cromer in his report referred especially to this circumstance, and stated that the solution of the problem of reinforcement and addition, which would practically double the storage of water and yet secure safety and strength in the structure, was due to Sir Benjamin Baker. In this case, too, the remarkable qualities possessed by Sir Benjamin Baker were illustrated afresh. Attention had been drawn by eminent mathematicians to possible causes of failure in dams, which had not been previously taken into account by engineers in their designs; and particular reference was made to the Assuan Dam. Quietly and deliberately the problem was studied by Sir Benjamin Baker, and when his decision was reached definite advice was given; which advice, we may be confident, will lead to satisfactory results, and prove an immense benefit to Egypt.

Cool, quiet judgment and restrained strength were his marked characteristics. His friends will not forget that, when the accident occurred to the roof of Charing Cross Station, Sir Benjamin Baker took the risk of personal inspection of the weakened structure in order to advise as to the best means of temporarily strengthening it; and upon him also rested the primary responsibility for recommending the ultimate removal of the roof. These are but instances of what happened again and again. In the hour of trouble Sir Benjamin Baker was a tower of strength on which men rested with confidence. His powers remained unabated to the end. During his recent visit to Egypt and the Sudan he suffered from illness, but he seemed to have regained health and to be as energetic as ever in mental processes. The end came suddenly, and those who knew him could believe that he would have wished it to be so. He worked to the end, and his last works were amongst his best.

Sir Benjamin Baker's connection with The Institution of Civil Engineers commenced in 1867. During his year of office as President in 1895–1896 the existing buildings were completed and the Institution was reinstated in its own home. He was the prime mover in carrying out important changes in the constitution of the Institution, which resulted in the election of the Council by

a postal ballot and the provision of a larger and more representative membership of the Council. He had much to do also with the re-arrangement and development of the system of working out the detailed business of the Institution by means of Committees; which system previously existed in outline, but necessarily required great extensions as the Institution grew in membership and in the scope of its work. On various occasions he served as representative of the Institution at important gatherings of Engineers; in this capacity he attended the Conference at the Chicago International Exhibition in 1893, his popularity with American Engineers making him a peculiarly fitting representative at that notable gathering. His devotion to the interests of the Institution was marked in many ways; by close attendance at the meetings of the Council and Committees, by readiness to serve as referee for Papers presented for reading or publication and by practical interest in other matters which, while domestic in character, have a great influence upon the well-being of the Institution. One of the last of his appearances at these Committees had to do with the important question of the site for the new home of the Institution, a matter on which his advice and assistance have proved of the greatest value.

Other learned and scientific societies showed their appreciation of his character and ability. He became a Fellow of the Royal Society in 1890 and served on the Council. Honorary Degrees were bestowed upon him by the Universities of Cambridge and Edinburgh and by other bodies. In the work of the Royal Institution he was deeply interested. He was a recognized leader in the work of the British Association and served as President of the Mechanical Science Section in 1885. He was made an Honorary Member of the American and Canadian Societies of Civil Engineers and of the American Society of Mechanical Engineers. He was a Member of Council of the Institution of Mechanical Engineers for some years before his death. Amongst British and foreign civil engineers his name will always stand high, and his memory will be cherished by his friends and fellow-members as a loyal and devoted servant of The Institution.

His name and fame were universally known. Throughout the British Empire may be found monuments of his genius and professional ability in the form of great works designed, supervised, or participated in by him. Outside the Empire the same thing is true, and on the American and African continents will be found evidence of his skill as an engineer.

Sir Benjamin Baker was elected an Associate of The Institution on the 3rd December, 1867, and was transferred to the class of

Members on the 29th May, 1877. He was elected a member of Council in 1882, Vice-President in 1891, and President in 1895, and he continued to serve on the Council until his death.

At the Council Meeting held on the 12th June, 1907, the following Resolution was unanimously adopted:—"That the Council on their own behalf and on that of The Institution record very deep regret at the death of their esteemed Past-President and colleague, Sir Benjamin Baker, whose intimate and continuous association with the work of the Council for a period of 25 years has been of the utmost value to this Institution as his engineering achievements have been of utility and benefit to the world."

NOTE.—In the foregoing memoir free use has been made (by permission) of the biographical notices published in *The Times*, 20th May, 1907, and *Engineering*, 24th May, 1907.

The following Papers were contributed by Sir Benjamin Baker to the Proceedings of The Institution :—

"The River Nile," vol. lx, p. 367.
"Cleopatra's Needle," vol. lxi, p. 233.
"The Practical Strength of Beams," vol. lxii, p. 251.
"The Actual Lateral Pressure of Earthwork," vol. lxv, p. 140.
"Railway Springs," vol. lxvi, p. 238.
"Steel for Tires and Axles," vol. lxvii, p. 353.
"The Metropolitan and Metropolitan District Railways," vol. lxxxi, p. 1.
Presidential Address, vol. cxxiii, p. 1.

CHARLES SNEATH ALLOTT died suddenly of heart-failure at Manchester on the 27th February, 1907. Born at Lincoln on the 17th May, 1842, he was the son of the late Mr. Joseph Allott, maltster, of Lincoln and Newark-upon-Trent. After serving a pupilage under Mr. L. H. Moorsom, on the Ringwood and Christchurch Railway, he joined the staff of the Fairbairn Engineering Company in 1862 and remained in their service until the liquidation of the Company in 1875, at which time he occupied the position of assistant manager. During this period he had charge of many important works, including the roofs of the Albert Hall, and Liverpool Street Station, London, the framework of the Spithead forts, and the bridges of the Intercolonial Railway, Canada.

He commenced practice on his own account in 1875, and amongst other work, he was responsible for the construction of the iron bridges of the Cheshire Lines Committee between Manchester and Combrook. His services were requisitioned by the Lancashire and Yorkshire Railway Company to report on the whole of their iron underbridges,

and he afterwards prepared drawings for the strengthening of a large number of these bridges and designed many new bridges for this and other railway-companies and public bodies, large cotton-mills for Brazil and China and other important works. In 1897 he took into partnership his son Mr. Henry Newmarch Allott and the practice was continued under the style of C. S. Allott and Son, since which time the firm have been responsible for many important works, including the buildings for housing the electrical plant at the new Stuart Street electricity generating-station of the Manchester Corporation and many bridges for the Salford Corporation and other public bodies.

Mr. Allott took a lively interest in church work and in voluntary schools. He was a prominent Freemason and served several offices in connection with the craft. He was also a keen golfer, and at the time of his death he was captain of the Manchester club.

He was of an exceptionally bright, genial and kindly disposition, and anyone needing advice and sympathy was sure to receive them at his hands. He was especially kindly to young engineers and was never happier than when trying to further the interests of deserving men.

Mr. Allott served on one of the Sectional Committees for the Engineering Conference in 1903, and also acted as President of the Manchester Association of Students of The Institution in 1897. He was a Member of the Institution of Mechanical Engineers, the Liverpool Engineering Society, and the Manchester Literary and Philosophical Society.

He was elected an Associate of The Institution on the 4th April, 1876, was subsequently placed in the class of Associate Members, and was transferred to the class of Members on the 21st December, 1880.

ANDREW BROWN, who died at Renfrew on the 6th May, 1907, at the advanced age of 82, was managing director of the well-known dredging-machinery and shipbuilding firm of William Simons and Company, of Renfrew, and was the oldest shipbuilder on the Clyde. Born in Glasgow on the 8th October, 1825, Mr. Brown's engineering career began at the age of fourteen, when he was apprenticed to Mr. John Neilson, Oakbank Foundry, Glasgow. After having successively served with Messrs. William Craig and Company, Messrs. Tod and Macgregor, and with the Caledonian Railway Company at St. Rollox, in 1850 he was appointed engineering manager to Messrs. A. and J. Inglis, Whitehall Foundry, Glasgow,

where he was engaged in the design and construction of various types of marine engines. In 1860 he joined the late Mr. William Simons as partner in the well-known dredger-building yard and engineering business at Renfrew. There he devoted himself to the study of problems relating to steam-dredgers and dredging-plant, the fruits of which have given his own name and the name of the firm with which he has been so long identified a world-wide reputation. He was the inventor of the "hopper" type of dredger, now extensively used, combining the properties of a dredger and barge in one hull. Although giving much time and study to the design and construction of many different types of dredger-plant, Mr. Brown never entirely confined himself to this particular branch of engineering. Thus, in 1861, he designed and constructed the Clyde passenger paddle-steamer "Rothesay Castle," which obtained the then exceptional speed of 20½ miles per hour, and which 40 years later, under a different name, was still in employment on the Canadian lakes. In the years 1867–8 he built and engined the Anchor liner "India," the first steamer on the North Atlantic route fitted with four-cylinder compound surface-condensing engines. He also achieved considerable success in the design of ferry-steamers, of which he built several for service on the Clyde and the Mersey. He embodied his experience of these vessels in a Paper[1] which was read and discussed at The Institution in 1894. It was chiefly, however, in connection with the design and introduction of dredgers and dredging-plant that Mr. Brown's ingenuity, experience, and skill were exercised. Mr. William Simons retired from active participation in the Renfrew business in 1880, and died in October, 1902. In July, 1895, the business was converted into a private limited company, and in 1900 it was constituted a limited-liability company, Mr. Brown becoming managing director.

Notwithstanding his close preoccupation with business affairs, Mr. Brown found many opportunities of identifying himself with the public life of the community of which he was so long a prominent member. As a large employer of labour, he was naturally brought into close relations with the inhabitants of Renfrew, who learned to appreciate his sterling personal qualities. For 35 years he served on the Town Council, and during 15 years of that period he was Provost of the burgh, being elected to that office no less than five times. In 1903 he presented to the town the Brown Institute to be used as a public library, recreation-rooms and Volunteer head-

[1] "Recent Types of Ferry Steamers." Minutes of Proceedings Inst. C.E., vol. cxviii, p. 256.

quarters. He also manifested in other ways his keen interest in local institutions; and by members of all classes of the community his death was felt as a personal loss.

Mr. Brown was elected a Member of The Institution on the 4th February, 1890.

SIR WILLIAM ROBERTSON COPLAND, LL.D., died from heart-failure on the 19th August, 1907, at his residence, Sandyford Place, Glasgow. Born at Stirling in 1838, he received his early education at the High School of his native town, and afterwards attended Glasgow University, where he distinguished himself in engineering subjects. His practical training as a civil engineer was acquired in Glasgow, under Mr. David Smith, to whom he served an apprenticeship from 1856 to 1860. Afterwards he joined the staff of the Edinburgh and Glasgow Railway Company, and was subsequently, for 4 years, Burgh Engineer of Paisley. In 1866 he began business in Glasgow, and soon acquired an extensive connection, particularly with corporate bodies. He made a special study of questions of drainage and water-supply, and constructed numerous important works, so that he came to be recognized, both at home and abroad, as a leading authority in these branches of civil engineering. Besides his practice in designing and carrying out public works, he acted from time to time as consulting engineer in connection with various municipal and county schemes. He occupied a high position as a Parliamentary witness and as an arbitrator in the settlement of claims for compensation, and cases of difference and dispute between parties. In this latter connection his quick grasp of affairs and sound judgment were greatly esteemed. He was appointed, by mutual agreement, standing arbitrator between the Glasgow Corporation and the Caledonian Railway Company in connection with the construction of the Central Railway, authorized by the Act of 1888.

Sir William Copland rendered valuable public service to Glasgow. His name was specially associated with the extension and organization of technical education, and with the erection of the new buildings of the Glasgow and West of Scotland Technical College. Sir William was chairman of the governing body of the college, and it is largely due to his individual effort that the college has reached its present high position. He also represented the Technical College on the board of the West of Scotland Agricultural College. As

a member of Glasgow University Court, he took a warm interest in the subject of university education, and, when the new medical and natural philosophy departments of the University were opened by the Prince of Wales, in April, 1907, he received the honorary degree of LL.D. In June, 1906, the honour of knighthood was conferred upon him by the King. Among the public offices he served was that of Deacon Convener of the Incorporated Trades of Glasgow, which gave him *ex officio* a seat on the Town Council for a period of 2 years.

He was elected a Member of The Institution on the 7th March, 1876.

GEORGE GORDON was born in 1828 at Arbroath and received his earlier education at the local Academy, studying later at Bonn and Wiesbaden, in Germany. He served a term of pupilage to the late Mr. J. G. C. Curtis, and while thus engaged attended a course of engineering lectures at University College, London. He was afterwards employed on Parliamentary surveys and other work as assistant to the late Mr. William Buld. In 1851 he was appointed Assistant Engineer on the Amsterdam Waterworks under the late Mr. Bland W. Croker, whom he succeeded as Chief Engineer in 1855. This office he held till 1859, when he was appointed one of the Resident Engineers on the Madras Irrigation and Canal Company's Works, becoming Deputy Chief Engineer in 1869. In 1871, when these works were approaching completion, Mr. Gordon received the appointment of Chief Engineer for Water-Supply in Victoria, Australia. As Chief Engineer he continued the works of the Coliban Water-Supply to Bendigo and other towns of the goldfields district, and also of the town supplies of Melbourne and Geelong and some provincial towns. In 1878 a political crisis brought about changes in some of the public departments, and Mr. Gordon, leaving the Government service, engaged in private practice in Melbourne. He carried out water-supplies for various provincial towns and was consulted with reference to hydraulic works in the neighbouring colonies of Tasmania, New South Wales and New Zealand. In 1884, in conjunction with the late Mr. A. Black, Surveyor-General of Victoria, he completed a series of reports to the Government of Victoria, on the supply of water to the northern plains for the use of stock and the domestic supply of the settlers. These schemes were for the most past subsequently carried out, and the value of the agricultural land was much increased. Mr. Gordon

paid a visit to England and the Continent between 1891 and 1894, and on his return resumed his practice in Melbourne, until 1899, when he retired.

He was the Author of two Papers published in the Proceedings on "The Value of Water and its Storage and Distribution in Southern India"[1] and on "Irrigation in Victoria,"[2] for which he was awarded a Telford medal and a Telford premium respectively. He died at Melbourne on the 25th February, 1907.

Mr. Gordon was elected a Member of The Institution on the 3rd December, 1867.

CHARLES HAYNES HASWELL died at his residence, 324 West 78th Street, New York City, on the 12th May, 1907, from the effects of a fall. Had he lived ten days longer he would have attained the age of 98 years. Mr. Haswell was the *doyen* of the engineering profession in America, and was probably the oldest engineer in the world actively engaged in the practice of his profession.

The son of Mr. Charles Haswell, of Dublin, the subject of this notice was born in New York City on the 22nd May, 1809. He received a classical education at schools in New York, and in 1828 he entered the steam-engine works of James P. Allaire, then the largest establishment of its kind in the country. In 1835 he was entrusted by the Commissioners of the U.S. Navy with the design and construction of the engines and machinery of the steam-frigate "Fulton," and on completing this work, he went to sea in the vessel as chief engineer. He was next assigned the duty of designing the steam-frigates "Missouri," "Mississippi" and "Michigan"; and subsequently was appointed chief engineer of the first-named vessel. Before her departure it was most unwisely proposed to substitute for her vertical smokestack 7 feet in diameter two horizontal smokestacks each 3½ feet in diameter. This was of course found quite ineffectual, and the original smokestack was subsequently replaced, but the warmth of Mr. Haswell's protest against such unscientific procedure and his refusal to apologize for what he considered the performance of a public and professional duty had led to his suspension. He was, however, later restored to active service and was entrusted with the responsible duties of Engineer-in-Chief of the Navy. In 1843, at the instance of Mr. Haswell, the

[1] Minutes of Proceedings Inst. C.E., vol. xxxiii, p. 376.
[2] *Ibid*, vol. cxlii, p. 326.

Act of organization of the Engineers corps was altered and the warrant of Engineer-in-Chief was replaced by a commission from the President, which was then conferred upon Mr. Haswell and confirmed by the Senate. He discharged the duties of this office for a period of 8 years, during which time he entirely reorganized the corps, which dates its greater efficiency from the reforms initiated during his term of office. In 1848, when marine engineering was in its infancy in the United States, Mr. Haswell gave signal proof of his ability by furnishing, without assistance, not only the first designs but the entire working-drawings of the steam-frigate "Powhattan," in which he introduced a number of practical improvements. He subsequently superintended the construction of this vessel, which did long and efficient service in the United States Navy. Political influence exerted against him led to his retirement from the position of Engineer-in-Chief in 1851, and shortly afterwards he left the service.

Returning to New York City Mr. Haswell engaged in consulting practice as a civil and marine engineer. He designed and built a number of merchant steamships and smaller vessels, including the earliest steam-launches and steam-yachts. He became a member of the Board of Councilmen of the city, and in 1858 he served as president of that body. He acted as engineer to several public bodies in New York, and was a trustee of the Brooklyn bridge during its erection.

When the Civil War broke out, Mr. Haswell, as a prominent citizen of New York, bore his full share in that momentous struggle. He acted as representative of a committee of his fellow-citizens at Washington, and later he saw active service under General Burnside in the expedition against Roanoke Island, where he commanded a gunboat. At the bombardment of Fort Bartow on the island, he ran his boat under the fire of the fort and hauled off the U.S.S. "Ranger," which had grounded on a shoal.

Mr. Haswell continued to practise his profession up to the day of his death. In 1898 he was appointed by the Board of Public Improvements to design and direct the grading and adaptation of Riker's Island for the service of the Department of Correction, and in 1902, at the age of 93, he was appointed Assistant Engineer to the Board of Estimate and Apportionment of New York City, in connection with which appointment he attended his office in the city for several years with the utmost regularity.

Many valuable contributions to engineering literature proceeded from his pen. His "Engineers' and Mechanics' Pocket-Book," commenced in 1840, passed its seventieth edition before the death

of its author. In 1860 he published a work on "Mensuration," and in the same year he commenced his interesting "Reminiscences of an Octogenarian of New York City," published in 1897. He also contributed Papers to several of the technical societies on both sides of the Atlantic, of which he was a member: among the most recent of these communications is that which he presented to The Institution in 1905, entitled "Note on a Method of Condensing Steam by the Use of Moderate Quantities of Water."[1] An earlier Paper by Mr. Haswell, "On Formulas for Pile-Driving,"[2] was published in 1894.

Mr. Haswell was an Honorary Member of the American Society of Civil Engineers, and a member of the American Society of Naval Engineers, the American Institute of Architects, the Society of Municipal Engineers of New York, the New York Academy of Science, and the Engineers' Clubs of New York and of Philadelphia. He was an honorary member of the Boston Society of Civil Engineers, and Dean of the Union Club of New York City. He was also a Member of the Institution of Naval Architects. He married in 1829 Miss Ann Elizabeth Burns, by whom he had three sons and three daughters. He retained his general good health and an erect figure until the last, whilst his intelligence was alert and his memory clear and reliable as in earlier years. He was a member of the American reception committee on the occasion of the visit of members of The Institution to the United States in 1904, and he took an active part in the excursions and meetings which were then arranged. His death removes a picturesque and unique personality from the ranks of the engineering profession in general and is an especia loss to his colleagues and friends in America.

Mr. Haswell was elected a Member of The Institution on the 5th May, 1885.

PETER SETON HAY, Engineer-in-Chief to the Government of New Zealand, died at Wadestown, near Wellington, on the 19th March, 1907, as the result of exposure whilst on a visit of inspection to railway-works in the North Island. Born in Glasgow on the 12th July, 1852, he arrived in New Zealand with his parents in 1860, and after attending the primary schools in Dunedin, he completed his education at Otago University, where he graduated in Arts in

[1] Minutes of Proceedings Inst. C.E., vol. clxi, p. 344.
[2] *Ibid*, vol. cxv, p. 315.

1876, and became Master of Arts with first-class honours in mathematics and mathematical physics in 1878.

Mr. Hay entered the Government service as a cadet in the Public Works Department in 1875. Four years later he was promoted to the position of assistant engineer in Dunedin, an office which he held for 5 years. He was transferred to Wellington in 1884, and was promoted to the rank of Resident Engineer in 1886. Ten years later he was appointed Superintending Engineer for the colony, a position which he gained by the conspicuous ability and sound practical knowledge and resource exhibited in all that he undertook. He was engaged during the foregoing period in the survey and construction of railways, the erection of bridges and viaducts, and the design and supervision of other public works in all parts of the colony. On the retirement of Mr. W. H. Hales early in 1906, Mr. Hay succeeded to the position of Engineer-in-Chief, and deep regret was felt throughout the colony at the untimely termination of his tenure of that important office.

Mr. Hay was elected a Member of The Institution on the 1st December, 1891.

ROBERT CHARLES PATTERSON was born in Melbourne in 1844, and obtained his professional training in England. Returning to Australia in 1864, he was first employed on railway construction in Queensland for Messrs. Peto, Brassey and Betts, and subsequently in Tasmania on the surveys for the Western Railway between Launceston and Ulverstone. From Queensland Mr. Patterson went to South Australia, where he held in succession the positions of Resident Engineer for Railways, Chief Assistant Engineer, and finally Deputy Engineer-in-Chief of the Colony. In 1871 he completed the overland-telegraph expedition to the Northern Territory, and he had the privilege of personally joining the wires which for the first time connected Europe with Australia by telegraph. After his retirement from this office, he took up contracting work in Tasmania, in which he was entirely successful, and shortly after completing a contract for the construction of part of the Derwent Valley Railway he retired from professional pursuits.

Mr. Patterson then turned his attention to public affairs, in which he continued to take a keen and active interest until his death. In 1900 he was elected one of the members for Hobart in the House of Assembly, and was returned for South Hobart in 1903. During

the ensuing session he was chosen leader of the Opposition, but after a few months he was obliged to retire on account of ill-health. It was, however, as member, and subsequently as Chairman of the Metropolitan Drainage Board, an office for which his training as an engineer and experience as a contractor eminently fitted him, that Mr. Patterson rendered his most valuable and lasting service to the community. He held the office continuously after his election to the Chair. Whilst presiding at a meeting of a committee of the Board on the 21st June, 1907, he suddenly became unconscious, and despite prompt medical aid, he died within an hour of the seizure, death being due to cerebral hæmorrhage. In private life, Mr. Patterson was generally esteemed as a man of wide intellectual and social interests, a stanch friend, and one ever ready to perform acts of kindness and charity.

He was elected a Member of The Institution on the 1st May, 1877. In the following year he presented to The Institution a Paper, "On the best methods of Railway Construction for the Development of New Countries, as illustrated by the Railway Systems of South Australia."[1]

HENRY THWAITES, who died suddenly at his residence, 3 Prince of Wales Mansions, Battersea Park, on the 10th October, 1907, in his sixty-first year, was the son of the late Mr. Otho Thwaites, of South Hampstead. Born on the 10th January, 1847, the subject of this notice was educated at University College, London. He was articled to Messrs. Ormerod, Grierson and Company, of Manchester, in 1864, and in the following year he became a pupil and subsequently an assistant to Mr. C. H. Gough, Resident Engineer on the South London, Peckham and Sutton branch of the London, Brighton and South Coast Railway. In 1870 he went out to South America as Engineer in charge of the survey for the Paturia Railway, U.S. Colombia, and proposed harbour-works at Santa Marta; and on his return home in 1871 he was appointed Assistant, and afterwards Resident Engineer, on the East and West Junction Railway. He afterwards acted as assistant to Mr. Robert Johnson on the Woodside extension of the London and North Western and Great Western Joint Railways.

In 1875 the Cape Copper Mining Company appointed Mr. Thwaites their Chief Engineer. On his arrival in Namaqualand his

[1] Minutes of Proceedings Inst. C.E., vol. lvi, p. 24.

chief work was the construction of the harbour at Port Nolloth and the survey and construction of the railway from the port to the mines. At the expiration of this engagement he went to Cape Town, and, after about a year's private practice, he joined the engineering staff of the Table Bay Harbour Board in 1879. He was appointed Chief Resident Engineer in 1883, and held the appointment until ill-health obliged him to resign in October, 1899. During his tenure of the office he was responsible for the carrying out of large extensions of the harbour and docks, designed by the late Sir John Coode, Past-President, and by Messrs. Coode, Son and Matthews, the Consulting Engineers. These works included an extension to the breakwater of 1,800 feet, a large iron jetty, and a new basin named the Victoria Basin, with extensive quayage and an area of 64 acres. The South Pier in the Victoria basin proved of very great value to the military authorities during the late South African War. Amongst other works he was entrusted with the design and construction of the new convict-station at Cape Town. To his instrumentality was due the installation of electric light at the docks as early as 1880; and the original installations, as well as the lighting of the Cape Town railway-station and the Houses of Parliament, were carried out under his supervision. The dock fire-brigade, of which he was captain during his whole term of office, was brought up to a high level of efficiency under his care.

Mr. Thwaites took a very keen interest in the welfare of all those under him. The Dock Recreation Society, which he inaugurated, and of which he was President until he left Cape Town, proved a great success, and the employees much appreciated his many efforts on their behalf. On his retirement on pension he returned to England, and lived quietly near London until his death. Mr. Thwaites was well known throughout the Cape Colony and South Africa generally for his kindness, generosity, and hospitality, and his death was a great loss to an unusually wide circle of friends, professional and personal.

He was elected a Member of The Institution on the 5th April, 1898.

ILLIUS AUGUSTUS TIMMIS, eldest son of the late Mr. Thomas Timmis, of Liverpool and Brazil, was born on the 23rd March, 1839, at Beoley, Worcestershire, and was educated at Cowley. He served an apprenticeship to Messrs. Ryder, cotton-merchants, Manchester, but early turned his attention to engineering, which he studied for several years, under the late Mr. George Davis, consult-

ing engineer, of Manchester, principally in connection with high-pressure boilers and engines. His inventive ability was early manifested in the application of smoke-consuming apparatus to locomotives, and subsequently he was responsible for the introduction or perfecting of a number of ingenious mechanical inventions, many of which have been widely adopted. These include improvements in the design, manufacture, and fitting of steel spiral springs, adapted for use in railway rolling-stock and on gun-mountings; a reversible lifeboat, which met with the approval of the Admiralty, Trinity-House, and Board-of-Trade authorities; a system of working railway-signals and points by electric power, transmitted by a long-pull electro-magnet, which he devised in conjunction with Mr. C. C. Currie; and the use of electricity for train-lighting, operation of brakes, and communication between passengers and guard. In 1878 he established himself in consulting practice in Westminster, and thereafter he was busily occupied in connection with the demand for his various inventions. His steel coil springs became well known in the engineering world and were extensively adopted in railway rolling stock and for other purposes, whilst his signalling apparatus and electrical installations for trains were taken up by railway-companies in all parts of the world, installations being designed for the London and North Western Railway, the Liverpool Overhead Railway, the Western Railway of France, and railways in Russia, Argentina, and Australia. His work obtained merited recognition at several international exhibitions, including the Paris Exhibitions of 1889 and 1900. In 1889 he took into partnership his son, Mr. Edgar William Timmis, under the style of I. A. Timmis and Son. In 1906 he undertook a tour through the United States and Canada for the purpose of introducing his inventions relating to rolling stock to the railway-companies of those countries, but on the return voyage on board the steamship "Etruria" he contracted pneumonia and died on the 18th December, 1906, aged 67. Mr. Timmis was a Member of the Institution of Mechanical Engineers and of the Institution of Electrical Engineers. In 1867 he married Honoria, daughter of the late Mr. William Udal, of Edgbaston.

He was elected an Associate Member of The Institution on the 5th April, 1881, and was transferred to the class of Members on the 8th May, 1888.

ALEXANDER GRAFTON, born on the 24th May, 1845, served an apprenticeship of 3 years to the late Mr. Samuel Worssam and subsequently spent 2 years with engineering firms in Paris. In

January, 1867, he joined the staff of Messrs. Appleby Brothers, and remained with them for a period of 12 years. During part of this time he was assistant manager of the firm's London works, and subsequently, for 4 years, he acted as their representative in Egypt, especially in connection with the Sudan railway contract. Between 1880 and 1882 he was a partner in the firm of Messrs. Lecoq and Company, of Hal, Belgium. In 1883 he founded the present firm of Grafton and Company at 113 Cannon Street, and 3 years later, in partnership with Mr. Henriques, he established the Vulcan Works, Bedford, which were designed and built by him. The partnership subsisted for about 5 years, and after its dissolution, Mr. Grafton carried on the business alone. He devoted his attention particularly to perfecting the design of the locomotive steam-crane constructed on the horizontal or turn-table principle with which the name of his firm is closely associated. Among the improvements which he introduced may be mentioned the loose roller-path, now widely adopted on steam-cranes. Mr. Grafton's designs for these appliances gained awards at several exhibitions and they formed the principal output of the Vulcan Works, the business of which developed considerably under Mr. Grafton's able direction. Latterly he did not enjoy good health, and his death, which was attributed to syncope, occurred suddenly on the 18th August, 1907, at Bedford.

Mr. Grafton was elected an Associate of The Institution on the 5th February, 1878, and was subsequently placed in the class of Associate Members.

FRANCIS EDWARD ALPHONSUS KENYON, son of Mr. John G. Kenyon, of Gillingham Hall, Beccles, was born on the 3rd August, 1872, and was educated at Downside College, Bath, and at Stonyhurst College, subsequently undergoing a course of instruction at the Crystal Palace School of Engineering. He obtained practical experience under Mr. William Leitch and Mr. Donald Arbuthnott on the staff of Messrs. Charles Brand and Sons, Contractors, during the construction of the Cruden branch of the North of Scotland Railway and the Highland Railway direct line to Inverness.

In 1898 he found employment under Mr. L. P. Nott, Contractor, on the Prince of Wales dry dock at Swansea, and after acting as engineer for Messrs. Brand and Sons on the Grangemouth dock-extension contract, he rejoined Mr. Nott's staff, and was engaged

as assistant agent on the Swansea south dock entrance-lock and pumping-station; on the extensive works of the Tranmere Bay development scheme; and as Agent in charge of the Princes Risborough and Grendon Underwood section of the Great Central main line. He was on the point of leaving England in June, 1907, to represent Mr. Nott in Canada, when his health failed him and after some months' illness, patiently borne, he died in a sanatorium at Penmaenmawr on the 27th August, 1907, in his thirty-sixth year and almost at the outset of his professional career.

Mr. Kenyon was elected an Associate Member of The Institution on the 4th December, 1900.

JOHN MENZIES was born in 1846 in Perthshire, where he received his education and obtained his early engineering training. In 1866 he was appointed deputy surveyor to the Edinburgh Road Trust, which office he held for a period of 3 years. In 1869, at the age of 23, he left Scotland to take up what proved to be a permanent residence in Wales, on receiving the appointment of manager and engineer to the Cambrian Quarries, Llanberis, Carnarvon. This undertaking was subsequently amalgamated with the Goodman and Cefndu quarries, and Mr. Menzies became managing director of the joint enterprise. Later he became part proprietor and manager of the Alexandra quarry, Nantlle Vale, and consulting engineer to the Coedmadog and South Dorothea quarries in the same district. He devoted special attention to the study of the geology of the county, and so thoroughly did he master the practice of slate-quarrying that he soon became widely recognized as an expert in all matters relating to the industry.

Apart from the claims of business, Mr. Menzies was an ardent worker in the field of public education, in which he took a deep personal interest. As a member of the Carnarvon County Council, he did yeoman service on various committees of that body, especially the Education and Finance committees, and he was repeatedly elected a county alderman. He also served on the Commission of the Peace for Carnarvon, and on the Carnarvon Board of Guardians and other local bodies. He was a member of the Carnarvon Harbour Trust for nearly 25 years, and he also served the office of chairman. He died at Pwllheli on the 21st May, 1907.

Mr. Menzies was elected an Associate of The Institution on the 3rd February, 1874, and was subsequently placed in the class of Associate Members.

FRANCIS JAMES ODLING, eldest son of the late Mr. Francis Odling, surgeon, of London, was born on the 12th November, 1845, and received his education at Highgate Grammar School and at King's College, London. His engineering training was obtained in the works of Messrs. Maudslay, Son and Field, and after spending some time in the timber trade, he resumed engineering work at Derby in 1879, as partner in the firm of Western and Company. In 1884, owing to industrial depression, the firm's works were closed, and in the following year Mr. Odling went out to Australia. Settling in Melbourne, he interested himself in mining and metallurgical matters, especially in the economical extraction of metals from their ores. In 1888 he became manager of the Pinnacles Mine at Broken Hill, and whilst there he devised a simple form of electromagnetic machine for the separation of metals from their ores, in which branch of research he became a pioneer in Australia. He followed this up with other and improved forms of separators, using both the dry and wet processes, and also perfected a new type of vanner. After his return to Melbourne, a company was formed for the commercial exploitation of these and other inventions patented by Mr. Odling. His later years were devoted almost entirely to scientific research, in which he displayed keen inventive ability and unusual fertility of resource. At the time of his death, he was engaged on a type of magnetic separator to be operated by polyphase current in substitution for a mechanical drive. He died suddenly at St. Kilda, Melbourne, on the 10th September, 1906, aged 60.

Mr. Odling was elected an Associate of The Institution on the 4th March, 1873, and was subsequently placed in the class of Associate Members.

ROBERT HENRY WHITE, Chief Engineer to the Leeds and Liverpool Canal Company, died on the 28th May, 1907, at the comparatively early age of 49. Born on the 28th April, 1858, he served an apprenticeship from 1874 to 1876 to Mr. W. H. Clemmey, then Borough Surveyor of Bootle, and on its completion entered the service of the Canal Company as assistant to his father, the late Mr. Charles White, who was Engineer and Estate Manager to the Company from 1869 to 1898. Subsequently he became Deputy Engineer, and on the retirement of his father in 1898 he succeeded to the appointment of Engineer to the Company, and occupied that position with conspicuous ability to the day of his death.

During the period that he was in the service of the Company, the Lancashire end of the canal was practically reconstructed, two large reservoirs were made and the whole of the Company's wharves and warehouses at Liverpool and other places were rebuilt and improved. To Mr. White, as well as to his father, the credit is due for the introduction and subsequent development of steam-haulage upon the canal, and for the many improvements which from time to time have been carried out. His genial disposition endeared him to all with whom he came in contact, whilst his sterling honesty and integrity of character earned for him their respect and esteem.

Mr. White was elected an Associate Member of The Institution on the 5th December, 1893.

ALFRED BACHE [1] was one of a large family of talented workers, male and female, who in the mid-Victorian period did much to enhance the reputation of Birmingham as a musical centre. He was born on the 5th August, 1835, at 12 Calthorpe Street, Edgbaston, Birmingham, being the second child of the Rev. Samuel Bache, a Unitarian minister, known outside his own denomination as the founder—in conjunction with the Rector of Birmingham and a layman—of "Hospital Sunday," which has since obtained world-wide extension. Alfred was educated at the Edgbaston Proprietary School, whence in 1852 he matriculated at London University, being first in Classical Honours and winning an Exhibition. Entering the engineering department at Queen's College, Birmingham, he graduated B.A (London) in 1854, and was third in the Honours list for Mathematics and Natural Philosophy. In the then new workshop at Queen's College many of the tools were forged, sharpened, and tempered by his hands. On leaving college in 1854, he entered the office of the Institution of Mechanical Engineers, then located in Birmingham, as assistant to the Secretary, Mr. W. P. Marshall, and in 1869 the Council of that Institution appointed him to be their Assistant Secretary. In 1877 the Institution was removed from Birmingham to London, and thus was terminated one of Mr. Bache's chief interests, for, under increased pressure of business, organ-playing was given up. He had been a pupil of Mr. Stimpson, organist of the Birmingham Town Hall, and when that gentleman was absent Mr. Bache gave the periodical organ-recitals for which

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[1] Much of the information embodied in this notice appeared in *The Cornishman*, September 12, 1907.

the Midland capital has long been renowned. At the time of leaving Birmingham, he was one of the finest organists in England. He was also an unusually proficient linguist, for besides Greek and Latin, he understood French, German, Italian, Swedish and Danish, accomplishments that stood him in good stead as a regular contributor for many years to the Foreign Abstracts of The Institution. Besides his abstracts, prepared with the painstaking care and accuracy which were the distinguishing marks of all his work, he contributed a Paper on "Peat Fuel in Scandinavia,"[1] published in 1901. He was also a clever draughtsman. In 1884 he was elected Secretary of the Institution of Mechanical Engineers in competition with a large number of others, and occupied that responsible position until 1898, when failing health obliged him to resign his post, after having served the Institution in various capacities for 44 years. Subsequently he went to live at Penzance, which had been his desire from his youth, and here he was first able, during a well-earned retirement, to devote his time to subjects of varied interest, mainly literary and musical.

Mr. Bache was a steady supporter of the Penzance Library, and as a member of the Committee presented the Library with several works, but his chief solace during the long and tedious illness which darkened his later years was his passion for music. This he retained to the last, taking great interest in the work of the Penzance Choral Society, of which he was a member of the Committee. He also supported the Penzance Military Band. Mr. Bache's career presented many features of resemblance to that of the late Dr. Pole, sometime Honorary Secretary of The Institution. Both were musicians to the finger-tips, constrained for special reasons to adopt engineering as a means of livelihood. Both were profound mathematicians, as so often happens with those who are proficient in musical harmony, and the best professional work of both was to be found in the quiet backwaters of literature rather than in the main current of professional rivalry; while the Alma Mater of both was a provincial town and not the metropolis.

In character Mr. Bache was modest and unassuming to a degree, and only those who knew him intimately enough to penetrate his habitual reserve knew what a lovable and engaging personality lay in the background. Few casual observers would have realized that the quiet and somewhat diffident gentleman, taking infinite pains, it may be, to inform a chance inquirer on some matter of ordinary moment, was in reality the possessor of solid learning that enabled

[1] Minutes of Proceedings Inst. C.E., vol. cxlvi, p. 229.

him to hold his own among the intellectuals of the day. His death, after long years of painful and exhausting illness, borne with exemplary fortitude, occurred on the 6th September, 1907.

Mr. Bache was elected an Associate of The Institution on the 4th December, 1877.

ARTHUR GIRAUD BROWNING, son of the late Mr. Charles Browning, M.D., was born at Sittingbourne on the 16th February, 1835, and was thus in his seventy-third year when he died at his residence, Spencer Lodge, Wandsworth Common, on the 19th October, 1907. After being educated at Bancroft's School, London, he was articled in 1849 to Mr. G. S. Herbert, Secretary of the South Eastern Railway Company. In 1854 he obtained an appointment on the staff of the late Mr. James M. Rendel, Past-President, which he held under his successors until 1859, when he entered into partnership with the late Mr. John Thomson, also a member of Mr. Rendel's staff. Under the style of Thomson and Browning a London Agency was established for several prominent engineering firms, a business in which the subject of this notice continued to take an active part until within a few months of his death.

Mr. Browning was a Fellow of the Society of Antiquaries and an enthusiastic student of Huguenot history. In 1873 he became a Director of the French Hospital, Victoria Park, and acted as Honorary Secretary of the Corporation from 1875 until 1898 when he was elected Deputy Governor. He was a Past-President of the Huguenot Society of London and an Honorary Member of the Huguenot Society of America.

Mr. Browning was elected an Associate of The Institution on the 2nd February, 1864.

BASIL PYM ELLIS, a partner in the firm of Messrs. John Aird and Sons, engineering contractors, died suddenly at Paris, where he was making a short stay, on the 5th October, 1907. He was 57 years of age. Entering Messrs. Aird's service in 1866, his connection with the firm extended over his whole engineering career. He was first employed as an assistant engineer on the construction of the Millwall docks and on extensions of the Southwark and Vauxhall waterworks. Subsequently he took part in the construc-

tion of the Birmingham waterworks, the Colne Valley waterworks, the Greenwich and Woolwich railway and other contracts. He was also connected with the building of the Beckton gasworks of the Gas Light and Coke Company, and the last work which he undertook in a subordinate capacity for the firm was the construction of the Bishopsgate and Aldgate section of the Inner Circle line. In 1878 he was taken into partnership, and thereafter he took an active share in the execution of the numerous important contracts of the firm in all parts of the world, amongst which may be mentioned the great Assuan dam in Egypt. Mr. Ellis was greatly liked and respected by his staff, to whom he was invariably kind and considerate. He married, in 1878, the eldest daughter of Sir John Aird, and leaves issue two sons and two daughters.

He was elected an Associate of The Institution on the 5th December, 1876.

Sir FRANCIS HENRY EVANS, Bart., K.C.M.G., died at his London residence, 40 Grosvenor Place, on the 22nd January, 1907, of angina pectoris, at the age of 66. Born on the 29th August, 1840, he adopted the engineering profession and obtained his practical training under the late Sir James Brunlees, Past-President, under whom he was employed on railway construction at home and in South America.

After spending some time in the United States, he returned home and decided to relinquish the pursuit of engineering and to devote his attention to banking. His firm was known as Melville, Evans and Company, and its operations were largely between this country and America. In 1880 he took a prominent place in shipping circles as deputy-chairman of the Union Steamship Company, under the late Mr. Alfred Giles, Past-President of The Institution, whom he subsequently succeeded as chairman, becoming also managing-director of the company. When the Union Steamship Company was amalgamated in 1900 with the Castle Line, it was Sir Francis Evans who carried through the difficult and important financial details of the transaction on behalf of the Union Company, Sir Donald Currie representing the Castle Line. On its completion, Sir Francis Evans joined the firm of Donald Currie and Company, the managers of the Union-Castle Line, and remained a member of it until his death. He was also a director of the International Sleeping Car Company, the Thames and Mersey Marine Insurance Company, and was chairman of the Elysée Palace Hotel in Paris.

For services rendered to the Government of Newfoundland in connection with the fishery dispute with France, and for other colonial services, he was made a K.C.M.G. in 1893. In 1902 he was created a baronet. In politics he was a Liberal, and was elected four times to represent the constituency of Southampton in Parliament. In 1900 he was returned at a by-election for Maidstone, which he continued to represent until the general election of 1906. He married in 1872 Marie de Grasse, daughter of the late Hon. Samuel Stevens, of Albany, U.S.A., and widow of Mr. Irving Van Wart.

Sir Francis Evans was elected an Associate of The Institution on the 3rd December, 1872.

*** The following deaths have also been made known since the 16th September, 1907:—

Members.

BROWN, THOMAS FORSTER; *died* 23 October, 1907.

FFORDE, JAMES; *died* 16 October, 1907.

FREITAS, ANTONIO DE PAULO; *died* 18 March, 1906.

GILBERT, CHARLES FREDERIC; *died* 25 December, 1906.

LISBOA, JOAQUIM MIGUEL RIBEIRO;

MACONCHY, GEORGE CAMPBELL;

MEDEIROS, VIRIATO DE;

(dates of death not known).

PAGE, GEORGE EDWARD; *died* 12 November, 1907.

SAWYER, FREDERIC HENRY READ; *died* 4 November, 1907.

SMITH, EDWARD BLAKEWAY; *died* 25 July, 1907.

SMITH, JOHN, *died* 1907.

STRACHAN, GEORGE RICHARDSON; *died* 20 September, 1907.

TAPAJOS, TORQUATO XAVIER MONTEIRO; (date of death not known).

Associate Members.

DEVENISH-MEARES, BASIL, *died* 5 October, 1907.

ETTY, THOMAS BODLEY; *died* 16 September, 1907.

GIFFORD, HERBERT JAMES; *died* 27 October, 1907.

HTU KAN; *died* 25 August, 1907.

LYNCH, EDWARD JAMES; *died* 30 November, 1907.

MACDONALD, DONALD; *died* 3 October, 1906.

TOPHAM, HANSON, *died* 7 November, 1907.

Associates.

ARDAGH, *Major-Gen. Sir* JOHN CHARLES, R.E., K.C.I.E., K.C.M.G., C.B.; *died* 30 September, 1907.

CLEGHORN, JOHN; *died* 24 September, 1907.

LINGARD-MONK, RICHARD BOUGHEY MONK; *died* 2 November, 1907.

Information as to the career and characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 7 December, 1907.

Sect. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

Planimeter. E. Dolezal.

(Berg- und Hüttenmännisches Jahrbuch der k.k. montanistischen Hochschulen Vienna, 1906, vol. liv, p. 293; 1907, vol. lv, p. 81.)

This monograph on the planimeter, covering 130 pages, is divided into four parts dealing respectively with (1) the history of the planimeter in Austria, (2) the determination of the constants and dimensions of the polar planimeter, (3) graphic representations based on area-equations, and (4) theoretical investigations. It concludes with an exhaustive bibliography of mechanical planimetry. The chief aim of the work is to show the important share taken 50 years ago in the history of mechanical planimetry by two Austrian mining engineers, A. Miller von Hauenfels, Professor at the Leoben School of Mines, and J. Stadler, mine manager at Eisenerz. The invention of the polar planimeter is usually ascribed to the Swiss professor, J. Amsler, who first published details of his invention in 1856, the invention having been made in 1854 when he was a student at the University of Königsberg and patented by him in 1855. In Austria, the invention of the polar planimeter is ascribed to Miller von Hauenfels and G. Starke, whose Austrian patent specification of 1855 is reprinted by the Author, the drawings accompanying the specification bearing the date of June, 1855. This instrument was based on polar coordinates; and it is noteworthy that it was so designed that the wheel moved over a spherical surface instead of over the paper, showing that the necessity of obviating the slipping of the wheel on the paper was realised, a drawback which was eliminated by Amsler 30 years later in his spherical planimeter. An improved form of planimeter was patented by Starke in 1856, and in the specification the term polar planimeter was employed for the first time. It is evident that, with regard to the discovery of the polar planimeter, two persons, Professors Amsler and Miller von Hauenfels, followed one and the same idea, and adopted it in instruments of almost identical form. Stadler in 1850 devised a rolling planimeter and a hyperbola planimeter, of which descriptions were published in 1857. His inventions remained, however, unnoticed and consequently had little influence on the development of mechanical planimetry.

B. H. B.

Logarithmic Calculating-Rules. Karl Lüdemann.

(Zeitschrift für Vermessungswesen, Stuttgart, 1907, vol. xxxvi, p. 241.)

Among the various forms in which logarithmic scales are utilized in technical calculations, the 10-inch slide-rule takes the first place, and next to that the most useful for engineering calculations is the logarithmic table, in which the scales are arranged in sections parallel to one another on a plane surface or on the surface of a cylinder. On the Continent it is usually believed that logarithmic slide-rules were invented by Jomard in 1816. This, however, is incorrect, as not long after the invention of logarithms Gunter, in 1620, placed logarithmic scales on wooden rules, and this "line of numbers" is the original form of the modern calculating-scale. Hutton, writing in 1785, states that the logarithmic lines were afterwards drawn in various ways. In 1627 they were drawn by Wingate on two separate lines sliding against each other so as to obviate the use of compasses. In 1627 they were also applied by Oughtred to concentric circles. They were then made in a spiral form in 1650 by Milburne, and lastly in 1657 in the present slide-rule form by Seth Partridge. Boucher in 1876 constructed his pocket-calculator in the form of a watch and provided it with a logarithmic scale in several lines, and with a fixed as well as a movable index-hand. The compasses are replaced by two indices in Fuller's slide-rule, patented in 1878, consisting of a cylinder which can be moved on a cylindrical axis held by a handle. The logarithmic scale is made in a spiral form. The second class of calculating-scales has the logarithmic-scales place on two movable concentric circles. The earliest instrument of this kind was made by Biler in 1696, and consisted of a semicircle of metal. The circular form was first used by Leblond in 1795. During the last 30 years calculating-rules in a great variety of forms have been introduced. Few of them, however, have come into practical use. The most recent forms are those of Puller and of Roether and Halden's calculex. The Puller calculator has a concentric circle, 477 millimetres in diameter, and is made of wood covered with cardboard for the graduation. The centre around which it turns is made of steel and brass. The cursor is made of glass and is provided with a magnifying-glass for reading. With this instrument the mean error in the multiplication of two four-figure numbers is $\pm 0 \cdot 014$ per cent. The Roether calculator is made in four sizes, with diameters of 220, 180, 110 and 70 millimetres respectively. The movable disk is made of prepared cardboard on a celluloid plate, and revolves on a plate of thick cardboard or wood. The cursor is made of transparent celluloid. With this instrument the mean error in the multiplication of two four-figure numbers was $\pm 0 \cdot 0079$ per cent. (size I), $0 \cdot 0216$ per cent. (size II) and $0 \cdot 0396$ per cent. (size III). The instrument in pocket size gives products of two two-figure numbers with an accuracy of $\pm 0 \cdot 115$ per cent. of

the result. The cost of this instrument varies between 9*s.* for the largest size and 3*s.* 4*d.* for the smallest. Halden's calculex is made with a diameter of 60 millimetres in a form convenient for the pocket.

B. H. B.

Gasoline Road-Roller.

(Engineering News, New York, 25 April, 1907, pp. 453–4.)

The 25-HP. 12-ton machine described can also be used as a traction-engine and as a stationary-engine to drive a crusher or other plant. A single-cylinder four-cycle horizontal gas-engine is mounted between two heavy plate-frames supported on the rear axle, and drives a crank axle having a fly-wheel at each end. A pinion on the crank-shaft gears with a spur-wheel outside the frames, and from a pinion on the shaft of this wheel there is a train of gearing to the main driving-gear on the rear axle. The engine-cylinder is cooled by oil circulation, the oil being passed through large air-cooled radiators placed beneath the cab. The cylinder-exhaust is at the bottom and is fitted with a muffler of the baffle-plate type to prevent noise and smell. The tanks have capacity for 2 days' work. The 3-foot 6-inch diameter front roller in two sections has a path 5 feet 10 inches wide, and the rear wheels, 6 feet in diameter with removable tires, are provided with devices, fully described, for studs to increase adhesion in traction-work, spikes for breaking up the surface preliminary to repair and rolling, and automatic scrapers to keep the smooth wheels clean when rolling.

There is no hauling of coal or water, no boiler-trouble due to bad feed-water, and no loss of fuel or time in banking at night or building afresh each morning. The machine can be handled by any intelligent man, no skilled driver being necessary.

C. O. B.

Dust-Prevention on Roads. Heim and Neir.

(Deutsche Vierteljahrschrift für öffentliche Gesundheitspflege, Braunschweig, vol. xciii, pp. 107–58.)

This article reviews fully the formation of dust on roads and streets, its analytical composition and its evils from a hygienic point of view. In regard to dust-prevention, the Authors describe the various methods now in use for road-construction, and full details are tabulated with respect to the initial cost, repairs and maintenance of the city roads of Dresden, showing that the total expenses, including first charges, interest and maintenance of the five classes of roads—macadam, small random sets, sets, concrete macadam and asphalt, vary as 1 : 1·06 : 1·17 : 1·27 : 1·74. The question of

palliative methods of mitigating dust-nuisances is then discussed, and the results of experiments with Westrumite are recorded. The dressing of the trial-roads was in every way successful, but was found to be 4 to 6 times more expensive than ordinary watering, so that a more general use on a large scale seemed prohibitive on account of expense. Various methods of the application of tar to road-surfaces are likewise dealt with, but the results have not proved satisfactory during the winter months when frost broke up the roads. The article finally discusses standard requirements for street-cleansing and the various types of road-cleansing machinery. It is fully illustrated by diagrams and photographs of the trial-roads and machinery.

F. R. D.

Hudson River Reinforced-Concrete Bridge at Sandy Hill, New York. William H. Burr, M. Am. Soc. C.E.

(Proceedings, American Society of Civil Engineers, vol. xxxiii, p. 394.)

This bridge, constructed of reinforced concrete, has fifteen spans, each 60 feet in the clear, making, with the two abutment-walls, a total length of 1,025 feet. The rise of each arch is 8 feet 6 inches, and the radius of the intrados 57 feet 6 inches. The piers are 6 feet thick at the top between the springing-joints, and 13 feet thick below the springing at the top of the concrete foundation. It is designed for both highway and passenger traffic, and there is also a single line of standard-gauge railway, the centre of the nearest rail being 4 feet 3 inches from the adjacent coping, while the total width between the coping-stones is 32 feet. Each span consists of five arch-ribs, over two of which the rails are placed. These ribs are heavier than the other three to provide for the increased load they are expected to bear, and are 3 feet square at the springing, and 3 feet by 1 foot 10 inches at the crown. In addition to its own weight the structure is designed to bear a snow-load of 12 lbs. to the square foot, and a moving load of 100 lbs. to the square foot over the roadway and sidewalk. The modulus of elasticity of the concrete was taken at 2,000,000 lbs., and that of the steel at 30,000,000 lbs. per square inch, and the compressive stress in the concrete does not exceed 500 lbs. per square inch. The steel reinforcement of each rib consists of four 3-inch by $2\frac{1}{2}$-inch by $\frac{5}{16}$-inch angles with not less than 2 inches of concrete outside. The steel angles and lattice-bars were built up on the side, the punching, riveting and bending being done by portable tools. The system of casting the concrete blocks forming the exterior spandrel-walls is perhaps novel. These blocks are formed with interior vacant spaces with corresponding channels along their beds and joints, and when laid in place a honeycomb-mass with internal channels is formed, so that by packing the exterior openings, thick grout may be poured in to completely fill

all the internal spaces. The internal recesses in the blocks are quickly and cheaply made by partially-filled paper bags of sand, which, when the block is set, may be punctured to allow the sand to run out. After the mortar has hardened the joints are raked out in the ordinary manner and pointed. The total cost of the structure was about £16,000, which was slightly increased by overtime work to hasten completion.

R. S. B.

Railway-bridge Construction in Chicago.

(Engineering Record, New York, 18 May, 1907, pp. 595–8.)

The reinforced-concrete bridges which form the subject of this article are being constructed to raise the Chicago, Burlington and Quincey Railway through Chicago in order to abolish level-crossings, and the portion, 6,000 feet long, specially described, carries eight lines, with occasional expansion where sidings and yards occur. A peculiarity deserving notice consists in the superstructure of the bridges crossing streets being constructed of huge reinforced-concrete slabs weighing nearly 37 tons, of which the maximum size is 24 feet 3 inches by 7 feet by 2 feet 9 inches, these being manufactured about 5 miles away and brought to site by special means duly explained. The material for the most part was 1 part cement to 4 parts pit-run gravel, from which all pieces exceeding 2 inches were excluded. The ordinary street-crossings, 66 feet wide, were spanned by two 24-foot 3-inch roadway-, and two 10-foot footway-openings, centre to centre, the slabs for the latter being 10 feet 9 inches by 7 feet by 1 foot 5 inches, the 7-foot width in each case providing for one railway line. Steel piers connected by plate-girders and concrete abutments support these. The reinforcement of the slabs, which was of Johnson corrugated bars, following the lines of tension at bottom and shear at ends, is fully shown in the illustrations. The most interesting part of the article comprises the description of the manufacture of the slabs, which were 90 days old before removal; their lifting by a 75-ton locomotive-crane, with a capacity of 40 tons at 30 feet radius by means of toggle-frames and special steel stirrups previously embedded in the concrete; the conveyance and unloading; and the details of the erection of the temporary supports; all of which are fully illustrated. These superstructures, a few of which vary in dimensions from the majority, have a practically noiseless floor, are easily inspected, and require no maintenance. The slabs cost \$11·80 (£2 9*s.* 2*d.*) per cubic yard to manufacture and \$2 (8*s.* 4*d.*) to place on the bridge, which is stated to be cheaper than in a similar steel superstructure. In work of the same kind, to be undertaken in 1908, it is proposed to use reinforced concrete also for the piers.

C. O. B.

Oakland Bridge, Pittsburg, Pa. W. Whited.

(Engineering News, New York, 16 May, 1907, pp. 528–30.)

This bridge is remarkable for its size—440-foot span with 70-foot rise—regarded as a steel arch without hinges. The method of adjusting the arch so as to give each member its initial stress is new, and has been found practicable and economical. The whole structure is 800 feet long between abutments, the superstructure being practically uniform throughout, viz., an ordinary plate-girder construction supported on steel columns which stand in concrete bases on the approaches and on the back of the arch in the middle. A description of these is given with numerous plates, but the interest lies in the substitute for hinges in the segmental arch ribs. The latter, two in number, are of box-girder shaped section in the top and bottom chord connected by two laced channels. The adjustment of the stresses was effected at the crown by cutting the bottom chord which was so designed that a powerful toggle could be applied to give the initial stress by forcing open the joint in the centre and inserting shims to hold it there. After the insertion of the latter, the toggles were removed and the chord so finished that its appearance was unaffected. The top chords at the springings were adjusted in a similar manner and shims were inserted between the ends of the chords and the cast-steel shoes to hold them. The method of determining by a micrometer-gauge the amount of stress applied in this way is fully explained with illustrations; the assumptions on which the stresses in the arch were calculated are then given; and the traveller and other appliances, and their operation in erection, are described.

C. O. B.

Railway-Bridge Erection without Interruption of Traffic.

E. Grasset.

(Revista de Obras Publicas, Madrid, vol. lv, p. 125. Figs.)

The railway from Saragossa to Alsasua crosses the river Aragon at a point near the junction of that river with the Ebro at Marcilla. The Aragon at that part is a wide river with low banks, and the bridge carrying the railway is about $\frac{1}{3}$ mile long, and consists of 16 steel girders each 98·4 feet long and supported by the abutments and 15 piers each composed of two tubes filled with concrete. The old girders were of the double Warren type and were supplied by the English contractors who built the line; careful tests were made with loaded trains and the original structure proved unsatisfactory for modern requirements. It was first proposed to stiffen the old girders, but finally it was decided to substitute entirely new girders. The article describes the details of construc-

tion, and there are photographic views of the means adopted for removing the old girders and fixing the new in position.

It appears that somewhat similar work was carried out on the bridge at Castejon previously, and the Author compares the methods adopted and the relative difficulties of the two cases. The details of the girder-work at Marcilla are shown in a large folding plate.

E. R. D.

Krossen Road-Bridge over the Oder.

(Centralblatt der Bauverwaltung, Berlin, 1907, pp. 6–7.)

The erection of a new steel road-bridge over the River Oder to replace an old wooden bridge is described, with details of the difficulties overcome. The new bridge, which is 540 feet long, is divided into two side bays of 154 feet each and a central bay of 232 feet span. The bridge is of cantilever type with Gerber hinged girders, and is so balanced that no anchorage was required at the abutments. On account of the long heavy autumn floods, which had seriously affected the stability of the cofferdams, it was found necessary to complete the masonry piers, necessitating the special precaution of covering the piers with tents warmed by means of coke fires. Further difficulties were incurred, as the right bank had to be erected at a higher level than the left bank, in order not to impede the traffic on the river. The left-bank girders and cantilever-arms were first completed, and then the right-bank girders and cantilever-arms were erected on screw-jacks, leaving the required clear headway of 12½ feet below the scaffolding. These latter girders were gradually lowered in place as the scaffolding below was removed. The article is illustrated by three photographic views of the bridge.

F. R. D.

Loetschberg Railway-Tunnel. PH. ZURCHER.

(La Nature, Paris, 11 May, 1907, pp. 376–8.)

The tunnel through the Loetschberg, the project for which was approved by the Swiss Federal Chambers in June, 1906, as forming part of a new railway to be constructed at a cost of £2,960,000 in a period of 5 years, is situated at a level of 3,937 feet above the sea. The gradients by which it is approached are 27 per 1,000, and as electric traction will be employed to operate the railway there will be no difficulty in running fast trains over the system. The works were commenced in October, 1906, and the Author, who is the Chief Engineer, describes some of the obstacles to the rapid progress which will be needed if the line is to be completed within the period specified. On the northern side at Kandersteg the enormous accumulation of snow and the frequent gales and avalanches ren-

dered the work of opening up the approach galleries one of great hardship. On the 7th March, 1907, the first drill worked by compressed air was started, but on the 14th of the month a falling avalanche produced such a wind-pressure as to unroof the electricity works and greatly interrupt progress. Only a few days later another avalanche fell and severed the main conductor conveying the current to the working-galleries. The difficulties on the south side of the mountain were equally great, and by means of photographs illustrations are given of the falls of avalanches which completely blocked the roads to the works, rendering it necessary to build a timber gallery to keep out the snowfalls. The rock found at the northern end of the tunnel is limestone belonging to the lower cretaceous formation, which has suffered extensive dislocations in past ages. At the south end the tunnelling is in gneiss, which is placed on a perfectly vertical bed. According to geological views, the central portions of the tunnel will pass through compact granite of the kind known as Gasteren granite, the outcrop of which may be seen on ascending the Kander above the Kandersteg near Gasteren village. The homogeneous structure of this granite encourages the hope that the tunnelling through this part of the work will not be very severe. It is anticipated that a temperature of 35°–45° C. may have to be faced in the deepest part of the mountain, which there rises some 4,900 feet above the tunnel. The total length of this tunnel is 14,991 yards, or about 8½ miles.

G. R. R.

Egyptian State Railways and Telegraphs.

(Report of the General Manager, 31 December, 1906.)

Mileage—	Kilometres.
4-foot 8½-inch gauge	2,037·426
Single line	2,411·828
Secondary branches and junctions	77·072
Sidings and cross-overs	659·831
3-foot 6-inch gauge	222·243
Sidings, etc.	19·892

There has been no increase except in siding-accommodation during the year.

	1906	1905
Gross receipts—	£E.	£E.
Passengers	1,486,931	1,316,826 [1]
Goods	1,749,231	1,652,687
Sundries	21,438	21,349
Total	3,257,600	2,990,862
Working-expenses	1,839,543	1,664,200
Net receipts	1,418,057	1,326,662

[1] To convert £E to £ sterling, multiply by 1·015.

	1906	1905
Detail of working-expenses—	£E	£E
Maintenance of way	471,114	440,302
Locomotives	590,537	560,277
Carriages and wagons	224,334	204,178
Traffic	328,233	282,134
General	225,325	177,309
Total per kilometre	795	721
Passenger-journeys, number	22,584,675	20,036,424
Goods-tonnage	3,981,652	3,645,768
Train-kilometrage	15,094,175	14,173,829
Engine-kilometrage	21,497,752	19,641,663
Receipts per passenger-train kilometre, millièmes	171	167
Receipts per goods-train kilometre, do.	273	263
Telegraphs (4,015·795 kilometres)—	£E	£E
Gross earnings	105,681	101,305
Working-expenses	91,715	74,707
Net receipts	13,966	26,598
Number of locomotives—		
4-foot 8½-inch gauge	547	518
3-foot 6-inch gauge	20	20
Coaching stock—		
4-foot 8½-inch gauge	958	889
3-foot 6-inch gauge	81	81
Wagons, etc.—		
4-foot 8½-inch gauge	9,618	8,917
3-foot 6-inch gauge	235	235

The capital stands at £E23,197,422.

It is stated, in reference to telegraph receipts, that those of 1905 have been credited with sums due from the Ottoman administration, so that the actual total amount earned in that year should be £E92,074. The General Manager refers to the transfer to the State in July, 1906, of 595 kilometres of agricultural standard-gauge lines in Upper Egypt with equipment, from the *Société Générale des Sucreries et de la Raffinerie d'Égypte.* Evidently the figures of working, etc., in the report do not include those of this system. The report, generally, is deficient in many detail figures usual in such documents, and has no map.

C. O. B.

Railways in India.[1]

(Administrative Report by the Railway Board, 1906.)

Mileage 31st December—	1906	1905
5-foot 6-inch gauge	15,548	15,028
3-foot 3⅜-inch „	12,149	11,959
2-foot 6-inch „	1,071	980
2-foot gauge	329	328
Total	29,097	28,295

799 miles of 5-foot 6-inch gauge and 182 miles of 3-foot 3⅜-inch gauge have been sanctioned during the year.

In the following statistics the money figures, except where stated, are in lacs of rupees. 1 lac = Rs.100,000; Rs.15 = £1.

	1906	1905
Gross earnings	4,411·73	4,168·09
Working-expenses	2,200·74	1,994·00
Net earnings . . .	2,210·99	2,174·09
Percentage of working-expenses to gross receipts	49·88	47·84
Train-mileage	114,554,000	107,045,000
Passenger-journeys	271,060,000	248,160,000
Do. average fare per mile . . .	Rs.0·0128	Rs.0·0128
Do. average distance travelled (miles)	39·43	39·90
Tonnage	58,869,000	54,936,000
Do. average rate per mile . . .	Rs.0·028227	Rs.0·027031
Do. average haul (miles). . . .	165·97	176·60
	Rupees.	Rupees.
Earnings per mile open	15,162	14,731
Do. per train-mile	3·85	3·89
Working-expenses per mile open . .	7,563	7,047
Do. per train-mile	1·92	1·86
Percentage of net earnings to capital .	5·83	5·92
Number of employees (slightly revised from last year's report)—		
European	6,850	6,529
Eurasian	9,326	9,181
Native	463,108	436,323
Capital expenditure	38,513·82	37,056·33

Rolling-Stock.

Locomotives—	1906	1905
5-foot 6-inch gauge	3,877	3,759
3-foot 3⅜-inch „	1,952	1,827
2-foot 6-inch „	155	131
2-foot gauge	61	58
Coaching-stock—		
5-foot 6-inch gauge	12,021	11,575
3-foot 3⅜-inch „	8,151	7,896
2-foot 6-inch „	589	519
2-foot gauge	292	277
Goods-stock, etc.—		
5-foot 6-inch gauge	72,173	69,163
3-foot 3⅜-inch „	40,681	39,508
2-foot 6-inch „	1,899	1,774
2-foot gauge	933	926

[1] All lines are included.

The report refers to additional and relinquished information in the present issue, thus rendering comparisons with the previous year less full.

The Board, in view of previous diversity, have adopted, for the future, British standard rail-sections as approved by the Engineering Standards Committee. They have also, in consequence of favourable reports on Australian timber, included this in tenders for sleeper-supply.

C. O. B.

Cape of Good Hope Government Railways.

(Report of the General Manager, 1906.)

	1906	1905
Mileage, 31 December	3,191	2,986
Average for year	3,074	2,807

204 miles 57 chains of new lines, eight in number, were opened during the year, 114 miles 77 chains being on the 3-foot 6-inch gauge and 89 miles 60 chains on the 2-foot gauge.

Earnings—	1906	1905
	£	£
Passengers	1,187,145	1,210,041
Parcels	116,924	114,424
Goods (including vehicles)	2,104,169	2,352,822
Cartage	82,334	86,724
Live-stock	138,985	130,093
Hire of rolling-stock to and from foreign administrations	16,784	*Dr.* 5,443
Mails	49,445	37,774
Telegraphs	13,692	13,988
Rents	55,607	48,418
Repayment of cost of damage by war	..	58,224
Loss on working guaranteed lines	7,685	..
Total	3,772,770	4,047,065
Working-expenses	2,981,350	3,076,920
Net receipts	791,420	970,145

		1906	1905
Passenger-journeys		20,691,686	20,611,384
Goods-tonnage		1,716,682	1,836,946
Live-stock	Head	1,148,405	1,031,542
Train-mileage		9,207,725	9,323,039
Engine-mileage		12,767,323	12,935,639
		d.	*d.*
Earnings per train-mile		98·3	104·2
Expenditure per train-mile		77·7	79·2

	1906	1905
Detail of working-expenses per train-mile—	d.	d.
Maintenance and new works	13·1	14·2
Locomotives	24·6	25·9
Carriages and wagons	7·4	7·1
Additional rolling-stock	6·6	6·5
Traffic	17·5	17·9
General	8·5	7·6
Total	77·7	79·2
Average passenger-travel . . Miles	16	16
„ goods . . . . . . „	163	186
„ passengers per train . No.	83	84
„ goods . . . . . Tons	73	79
	d.	d.
Receipts per unit-mile, passengers	0·864	0·895
„ „ „ goods	1·699	1·565
Expenditure per unit-mile, passengers	0·755	0·704
„ „ „ goods	0·956	0·927
	£	£
Capital expenditure	31,994,679	29,973,024
„ „ per mile	9,801	10,038
Rolling-stock, 3-foot 6-inch lines—		
Locomotives	653	668
Passenger-carriages	950	924
Goods-trucks	10,215	10,358
Other vehicles	78	77
Rolling-stock, 2-foot lines—		
Locomotives	14	14
Petrol-motor carriages	2	1
Passenger-carriages	38	31
Goods-trucks	172	172
Other vehicles	3	3

The general manager explains the decrease in goods-haul as being due to the opening of new connecting lines. He refers to the report of a commission initiated by Parliament as to the advisability of change in administration, and of obtaining improved consideration as to future extensions. He agrees with the conclusions of the Commission, but not with the means proposed, which, however, are not quoted, preferring the establishment of a board of three commissioners superseding a general manager. Two extracts from the report of the Victorian Railway Commissioners for the year ending 30th June, 1906, are appended in support of the views stated.

C. O. B.

Central South African Railways.

(Report of the General Manager, 31 December, 1906.)

	1906	1905
Mileage at end of year—		
3-foot 6-inch gauge, single	2,106½	1,736½
,, ,, ,, double	45	45
,, ,, ,, treble	7¼	7¼
Total	2,158¾	1,788¾
2-foot gauge, single	26¾	0
Total	2,185½	1,788¾
Average miles worked	1,689	1,542
Lines under construction	406½	643½
Earnings—	£	£
Passengers and parcels	1,259,277	1,348,827
Goods, etc.	3,522,772	4,015,792
	4,782,049	5,364,619
Working-expenses	2,878,713	2,834,475[1]
Net receipts	1,903,336	2,530,144
Percentage of working-expenses to gross receipts	60·2	52·5
Train-mileage	7,002,020	7,321,618
Engine-mileage	8,341,285	8,840,552
Number of passengers	7,312,846	6,871,547
Livestock, head	712,720	679,662
Goods, general, tons	4,083,290	3,904,717
,, departmental, tons	576,999	648,671
Receipts per train-mile	163·9*d.*	175·9*d.*
,, per open-mile	£2,831	£3,479
Working-expenses per train-mile— Locomotive department 30·5*d.*; Maintenance 14·2*d.*; Telegraphs 0·5*d.*; Traffic 22·1*d.*; General 8·1*d.*; Funds for renewals 23·3*d.*	98·7*d.*	92·4*d.*
Working-expenses per average open-mile	£1,704	£1,827
Capital	£23,877,092	£23,424,309
Number of locomotives	471	481
,, carriage-stock	449	463
,, goods, etc.	7,404	7,615

The number of employees was: Whites, 6,163; Natives, 7,988.

The general remarks in the Report refer, among other matters, to the planting of timber (red ironbark) for future sleeper-renewal, and to the large sums set apart for depreciation generally in the state-

[1] Discrepancy between this and the figure shown in the 1905 Report is explained in one of the statements appended to the Report.

ments of expenditure. Besides the usual tables and diagrams the Report is profusely illustrated by drawings of engineering works and rolling-stock and by maps. C. O. B.

Lighting of Railway-Trains by Incandescent Gas-Lamps.

H. Guérin.

(Le Génie Civil, Paris, vol. l, pp. 349–51.)

The Eastern Railway Company of France, with a view of ascertaining the best type of incandescent gas-burner for illuminating passenger-carriages, caused a very complete series of experiments to be made, photometer-gaugings of the light emanating from various burners being taken at, in some cases, as many as thirty different points in each compartment, all about the level at which a newspaper would be held while being read. The chief interest of these experiments lies in the comparative tests between the ordinary or upright type of mantle and the inverted form. In all the experiments the supply of gas was 15 litres (0·53 cubic foot) per hour and the pressure was 200 millimetres (7·80 inches). The Mascart photometer was used throughout. The result of the experiments was to show that the penetrating power of the light from the inverted burner was by no means so great as that from the ordinary type. One standard candle, at a distance of 1 metre, was taken as the unit of intensity, and in one typical experiment, a single central lamp being used, while, in the case of the inverted burner, 14 units were gauged at the points, practically, below the burner the intensity was less than 3 units in the corners of the compartment. A similar experiment tried with the ordinary type of mantle gave 12 units at the points below the lamp and 4 units in the corners of the compartment, a drop in the one case of 11 units or 78 per cent., and in the other of 8 units or 66 per cent. The inverted burner was found to compare disadvantageously with the ordinary type in a variety of other ways, notably that (*a*) in the event of breakage of mantle the light was completely extinguished, while with the ordinary type sufficient of the mantle remained in position to give a reasonable light; (*b*) it was much more easily broken, the respective lives being given as 19 and 65 days; (*c*) it was considerably dearer in first cost. The Western Railway Company of France adhere to the inverted type, but they use a poorer gas. The experiments have convinced the Eastern Company that the ordinary or upright type of burner should be adopted.

I. C. B.

Electric Motors v. *Steam Locomotives.*[1]

LEWIS B. STILLWELL and HENRY ST. CLAIR PUTMAN.

(Proceedings of the American Institute of Electrical Engineers, New York. January, 1907, pp. 1–64.)

The Authors of this lengthy and elaborate Paper are of opinion that the electrification of the trunk-lines of railway in the United States will be taken in hand at an early date and will proceed much more rapidly than is probably anticipated. They base this opinion on a minute investigation they have carried out comparing the steam locomotive with the electric locomotive, and in their Paper they give the result of this investigation by (1) recording certain facts relative to heavy electric traction which have been established by experience; and (2) presenting calculations of relative costs of steam and electric traction in railway-service based on these facts. Having thus established their position they proceed (3) to discuss the manner in which electrification should be carried out, emphasizing "the transcendent importance of standardizing electric-railway traction-equipment as rapidly as may be consistent with progress"; and (4) raise the question whether a frequency of 25 or 15 cycles per second should be adopted in railway operations by alternating-current motors. These points (1 to 4) are stated by the Authors to be the fourfold object of their Paper.

The more important considerations which affect gross earnings in respect of passenger-service are stated to be—frequency of service, speed, general comfort of passengers, safety, reliability of service, increased capacity of line, frequency of stops, and convenient establishment of feeder lines. Each of these considerations is discussed at length, and important data are given by way of illustration, as for instance, in the matter of reliability, the records kept by the Manhattan Railway show that for corresponding periods for steam and electric traction on this railway the car-mileage per train-minute delay was 2,243 and 4,268 respectively. This matter is further illustrated by several examples of the preference shown by the public to the electric road and the enormous development of passenger-business produced. Thus, in the case of the competitive steam and electric railways connecting the cities of Cleveland and Loraine, 26 miles apart, the steam line carried 42,526 passengers in 1895, but in 1902 only 9,795 passengers, whereas the electric line carried in the latter year 3,896,902 passengers. These matters are further illustrated by data, extending between 1872 and 1906, giving the fares paid and the car-miles run on the transport-lines in New York city.

The Authors are of opinion that the standardization of electric-railway traction-equipment, so far as it affects the interchange of railway-stock by the various companies, should be taken in hand

[1] See also following Abstract.

without delay, and they suggest that agreement should be arrived at in establishing standards of practice as regards (*a*) location of third rail; (*b*) location of overhead-conductor used with single-phase alternating-current system (the Authors are of opinion that this system is the best); and (*c*) frequency of alternating-traction systems.

The Paper concludes with a discussion of the relative merits of 25 and 15 cycles per second. Amongst the principal advantages of the former the following are quoted. The design of turbo-generators is facilitated in the matter of revolutions, the lighting of yards and shops by incandescent lamps is easier, and there is some advantage in respect of the ratio of tractive effort to the weight on the drivers. The great advantage, however, of 15 cycles per second is due to the fact that, within given dimensions, a materially more powerful, efficient, and generally effective single-phase motor can be constructed for 15 than for 25 cycles. Owing to this the Authors estimate the saving thus effected would be approximately $2,500 per motor-car. This saving, however, must be discounted by the increased costs in the power-house. The Authors estimate that the total saving for the entire railway system of the United States would be $14,000,000 (about £2,800,000).

H. R. S.

Electric Motors v. *Steam Locomotives.* (*Discussion.*)[1]

LEWIS B. STILLWELL and HENRY ST. CLAIR PUTMAN.

(Proceedings of the American Institute of Electrical Engineers, New York, March, 1907, pp. 235–301.)

The appendix to the Paper referred to in the preceding Abstract deals with power-house output and load-factor, and the data are taken from the report of the Interstate Commerce Commission. It is assumed that the power-houses will be located on the average at intervals of 300 miles, so that the transmission-lines will be 150 miles long, the transmission-voltage being 60,000 volts. Calculation shows that the average load at each power-house will be 2,100 kilowatts, the power-factor 0·97, and the maximum momentary peak 3,000 kilowatts. The total power-house capacity required for the whole of the United States is estimated at 2,100,000 kilowatts.

The discussion was opened by Mr. Frank J. Sprague, who did not agree with the Authors that the single-phase alternating system was the only one worth considering, and thought that a high-voltage direct-current system would compete favourably. Messrs. B. G. Lamme, W. B. Potter, N. W. Storer, and many others, agreed with the Authors that, on the whole, 15 cycles per second were preferable to 25 cycles for railway work, the principal advantage being the

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[1] See also preceding Abstract.

greater output of motors possible, the size and weight being limited. As regards tractive effort, Mr. B. G. Lamme thought there was not much difference between the two cycles, but Mr. B. W. Potter stated that, with the motors mounted on springs, the available tractive effort at 25 cycles was 80 per cent. to 90 per cent., and with 15 cycles 70 per cent. to 80 per cent. of the maximum. Mr. C. L. de Muralt gave important information in respect of the comparative speed and power characteristics of various steam and electric locomotives in actual work, and exhibited these by means of curves. For steam locomotives he gives the following formula:—

$$\text{Tractive effort} = \frac{161 \times \text{heating surface in square feet}}{\text{speed in miles per hour}} - \frac{3 \cdot 8\, d^2\, L}{D},$$

where d is the diameter of the cylinder in inches, L the length of the stroke in feet, and D the diameter of driver in feet. The following are some of the conclusions he has come to. The continuous output of the steam locomotive is practically its maximum output on account of the impossibility of forcing the boiler for any lengthened period; electric locomotives, on the contrary, can sustain overloads of considerably greater magnitude for much longer periods. The characteristic curves of direct-current and single-phase alternating-current locomotives are very similar to those of the steam locomotive, that is, they reduce their speed when called on to haul an increased load. The three-phase alternating-current locomotive, however, accommodates itself to increased load without any great diminution in speed. He gives the following Table comparing the tractive effort of various locomotives at 60 miles an hour:—

	Maximum Tractive Effort.	Weight of Locomotive and Tender.	Trailing-Train Weight.
	Lbs.	Tons.	Tons.
Single-phase (electric)	4,250	85	165
Direct-current (electric)	6,000	95	258
Atlantic type (steam)	9,250	161	382
Pacific type (steam)	9,750	175	398
Three-phase (electric)	9,375	95	457

In his opinion a point has been reached on certain railways where the trains are so heavy, the speed so high, and the traffic so great that the steam locomotive is up to the limit, so that electrification becomes a necessity unless new lines are added. Not only are electric locomotives more powerful than steam locomotives of the same weight, but two or more electric locomotives can be coupled together by multiple-control connections, and can be worked as one locomotive by one man. Mr. W. I. Slichter gives details of the costs (expressed in percentages) of a 25-cycle compared with a 15-cycle installation adapted to an interurban railway, and shows that the

latter is slightly the more expensive. For main lines, however, he estimates that 15 cycles will be cheaper. Mr. W. S. Murray gives in great detail the results of data he had collected for 18 months of the cost of steam and electric locomotives, both for passenger- and freight-service, and he shows that, for the New York division of the New York, Newhaven and Hartford Railway, the saving due to electricity in coal alone will be $341,470 (about £68,000).

H. R. S.

Broken Rails.

(Railway Age, Chicago, 24 May, 1907, pp. 796–7.)

An epidemic, as it is called, of breakages especially in the heavier sections of American rails is dealt with and the causes are discussed. The first of these is stated to be excess of phosphorus, the specifications allowing 0·10 per cent. causing brittle steel. The prospect of a supply of low-phosphorus rails rests on the substitution of the basic open-hearth furnace for the Bessemer converter. Open-hearth steel low in phosphorus and sulphur admits of a higher percentage of carbon, thus increasing the elastic limit, deflecting less and wearing longer.

A second cause is due to the large section and methods of manufacture, piped rails being caused by the segregation of impurities in the upper portion of the ingot and failure to remove enough of them, while long crop-ends produce an excess tonnage of scrap which must be smelted, and there is a constant tendency to leave in a large proportion of impurities which, when rolled out into pipes, produce a weak rail. Another defect, failure of the flange in a crescent-shaped fracture, has been traced to the ambition of the mill-manager to roll still faster and cheapen the product. A further cause in the case of the heavy rail where the head may be $1\frac{3}{8}$ inch thick and the flange $\frac{5}{16}$ inch, is the heat-treatment in rolling, causing, through inequality in cooling, a coarse crystalline structure in the rail-head. It is understood that new mills are being designed to roll slower, the rolls being so shaped that more work can be done on the rail-head while cooling down to the critical temperature. Meanwhile, many of the western lines are continuing to use lighter sections which show less breakage.

Another article in the same issue gives large-size sections of 90-lb. rails which have failed, and a chemical analysis of six specimens, in three of which the phosphorus amounted to 0·107, 0·111 and 0·108 per cent. There are also microphotographs showing texture of heads.

C. O. B.

New Jersey Central Railway Goods-Shed.

(Railway Age, Chicago, 10 May, 1907, pp. 738–40.)

The peculiar oval form designed for this terminal has been adopted to save cost of land by minimizing space. The railway-wagons arriving from lighters on the Harlem River are to be delivered on a transfer-bridge, and are then to be run round outside the oval terminal shed, delivering their loads through doors to its 40-feet wide platform, running nearly round the building inside. From this they will be transferred to the central courtyard for teams, access to which cuts the building near one end of the oval, crossing two of the approach tracks. In connection with the latter and to afford further loading- and unloading-accommodation, are seventeen dead-ends with buffer-stops, in seven double and one triple road, giving access to paved approaches between them communicating with the adjoining street. A very complicated arrangement of switches is involved so as to gain access to all these with a minimum radius of curvature of 90 feet, and in order to secure (excluding free shunting-line) a capacity of 110 cars, the total area being enclosed between an irregular space of 545 feet to river-frontage, 310 feet west, 350 feet north and 490 feet east. The building which is nearest to the shortest side forms the outer ring of the oval, 194 feet by 166 feet, and is of steel with two transverse fire-walls of concrete dividing the ring into three sections. Full particulars of these and an enumeration of the equipment and appliances are given, with illustrations.

C. O. B.

Reinforced-Concrete Retaining-Wall Design. E. B. Bone.

(Engineering News, New York, 25 April, 1907, pp. 448–52.)

The mathematical investigations, figures, and numerous graphic diagrams supplied by the Author chiefly refer to the inverted-T form of wall, the heel and toe of the base entering largely into the means of stability. By the use of this section the unit-pressure can be kept well within the limits of the bearing power of the earth on which the wall is built. Such flexibility of design is not possible with a gravity-wall. In designing the latter, the resultant pressure must be made to strike the base within the middle third to avoid tensile stresses in the back of the wall. But in a reinforced wall, as described, this tension is provided by the heel acting as a cantilever beam, and thus the direction of the resultant is not so limited, but may strike near the end of the toe, or if the foundation be doubtful, the extension of the toe will meet the case. The theory of design under this system is fully gone into, and the graphic diagrams plotted from the results of the formulas show for a given depth below the top, the minimum thickness of wall and sectional area

per lineal inch of steel-reinforcement. Another diagram shows the length of base required for different lengths of heel and different heights of wall, for solid rock and for 12,000-lb.-per-square-foot foundations, accompanied by a table giving lengths of heel required to prevent sliding.

Other diagrams give the depths of heel and toe, and base reinforcement for different pressures and heights.

Ordinary shaped retaining-walls with counterforts are then dealt with, but more briefly, the Author deprecating this form in concrete as less economical in view of the more elaborate moulds required.

There is an illustrative paragraph on factors of safety, having in view what the Author terms factors of ignorance in this case, and the uncertain thrust due to hydrostatic pressure or to freezing, &c.

C. O. B.

Tests to Destruction of Reinforced-Concrete Beams.

(Schweizerische Bauzeitung, Zürich, vol. li, p. 198. 17 Figs.)

A Paper was read in February, 1907, by Professor E. Mörsch before the Zürich Society of Engineers and Architects on the subject of reinforced-concrete beams, and this induced the firm of Wayss and Freytag, of Neustadt, to carry out tests to destruction on some beams of that character. The results of these tests are given in the present article, which is illustrated by drawings showing the details of the reinforcement used, and also by photographs of the beams after they had been tested in order to show clearly how they gave way under the stress. The chief point was to test for shearing, and therefore bending and torsional stresses were eliminated so far as possible. Twelve test-objects were made, each consisting of a flat section of floor or platform supported by two ribs or girders, the whole forming a solid mass of concrete in the proportion of 1 : 4½, reinforced by iron bars; the concrete was in all cases three months old. The floor-area was in every case 7·87 feet wide, by 8·85 feet long between the edges of the supports, the floor itself was 3·94 inches thick and the depth of each of the two ribs measured from the underside of the floor was 9·84 inches. The width of the ribs varied, and the reinforcement was different in each test-object. Six of the objects were tested with distributed loads, three were tested with two concentrated loads, each load being placed on a line one third of the span from a support, and the remaining three objects were tested with a load concentrated on the centre line of the span. The sides of the ribs were painted white so that the finest cracks were visible as soon as they were formed. The Author considered that on theoretical grounds the bars would give better results if bent at 45° upwards near the supports rather than when laid horizontal near the underside of the ribs and merely provided with stirrups. This view is fully confirmed by the results of the tests which are given in tables. These results cannot be abstracted, but it may

be said that the maximum breaking-load of the best specimen with a distributed load was 33 tons, which is equal to about 9½ cwts. per square foot of floor. Each rib was in this case 5·5 inches wide, and was reinforced by three bars 0·59 inch in diameter and one bar 0·7 inch in diameter without stirrups. The Author, however, strongly recommends the use of stirrups.

E. R. D.

Shear Tests of Reinforced-Concrete Beams. Mörsch.

(Deutsche Bauzeitung, Berlin, 1907, 13 April, pp. 207–12; 20 April, pp. 223–8; and 1 May, pp. 241–3.)

The author describes the tests of twelve reinforced-concrete girders of different construction. The beams were 9 feet long, and were made of concrete in the proportion of 1:4½ of cement and sand. They were tested 3 months after manufacture. The reinforcement consisted of ¾ round iron with plain and hooked terminals, "Thacker" bars arranged in various ways, the one half of the beams having additional stirrup-irons. The loads applied were continuous, two symmetrical and one central load. The summarized results of the tests showed that it was absolutely necessary to coat the test-beams with a whitewash solution in order to ascertain the first signs of hair-cracks; that these hair-cracks need not be considered of importance in correctly designed work where the concrete is not under tension; and that further tests are required in order to ascertain the best position for the reinforcement, as the influence of the use of stirrups was clearly shown, for whereas the stirrups in many cases have no statical functions to perform, they may nevertheless be of service as a factor of safety and as means of making better connections between beams and floorings, and are necessary in the case of suspended reinforcement.

The article contains tables of tests, drawings of the beams, and photographs showing the various stages of the experiments.

F. R. D.

Comparative Tests of Cement-Mortar. Grübler.

(Zeitschrift des Vereines Deutscher Ingenieure, Berlin, 2 February, 1907, pp. 176–84.)

In order to clear up various points in the determination of the elastic constants of cement-mortar and kindred substances the Author devised a special form of apparatus for carrying out the tests. The specimens consisted of circular rings held between two steel disks, the pressure being applied hydraulically to the interior of the ring. The load was gradually applied by screwing a steel spindle into a watertight compartment formed over the

interior of the specimen between the two disks, a thin rubber ring being used at the joints, and the pressure being read off directly in an automatic maximum recording pressure-gauge.

A special pattern of extensometer giving the increase in circumference of the specimen was also employed for determining the elastic constants, etc., of the materials under test. The article is accompanied by a number of diagrams, illustrations, curves and formulas. C. J. G.

Prevention of Freezing in Concrete by Calcium Chloride.

R. K. Meade.

(Engineering Record, New York, 20 April, 1907, pp. 501–2.)

The Author made a series of experiments, of which particulars are given, showing that as solutions of calcium chloride freeze at a much lower temperature than those of salt, which is commonly used to prevent freezing in concrete, it is not only much more effective for this purpose, but improves the concrete in other ways, such as water-proofing and soundness. There are four Tables in connection with the briquettes experimented on, giving temperatures, age and strength with and without the addition of calcium chloride, and with various percentages of it, and results where the concrete was alternately frozen and thawed. The conclusions arrived at were that the addition proposed prevents freezing, allows full strength to be developed, delays setting and increases impermeability.

C. O. B.

Treatment of Railway-Sleepers. L. Bush.

(Engineering Record, New York, 20 April, 1907, pp. 482–5.)

The serious diminution of timber-supply in the United States renders it necessary to prolong the life of sleepers, which, apart from the adoption of broken-stone ballast in preference to gravel, and of steel tie-plates, both of which are advocated, must be effected by treatment. The subject is dealt with under four main heads:—(1) native timbers which are available; (2) best methods of preparing these for treatment; (3) methods and cost of the latter; and (4) plant for treatment. Under the first head the quality of the available supply is discussed. The second treats of three methods of seasoning: simple exposure to air, kiln-drying, and evaporation by steam-pressure. The second method being condemned as expensive and as objectionable through the too great rapidity of the process inducing warping, most consideration is given to the third. The operations in use for this purpose on the Southern Pacific and Union Pacific railways are given in full, in which the main features appear to be the preliminary adoption of 90 days' air-

seasoning, and the application of a vacuum before the admission of the live steam. An extract from a Report of Professor Hatt of Purdue University follows, in which objection is made to a high degree of steaming, this, however, depending on the quality of the wood and its degree of seasoning. The opinion of Mr. Faulkner, who is in charge of the timber department of the Santa Fé line, is also quoted in reference to the methods in use in warm and humid climates, and the reasons are given why he has abandoned the steaming-process for air-seasoning.

With regard to the third heading, five processes are described in detail and discussed:—the zinc-chloride or Burnettizing; the Wellhouse or zinc-tannin; the Bethell or creosoting; the Rueping; and the zinc-creosoting. The first is condemned as, though cheap, deficient in permanency; the second is a modification of the first, but more costly; the third is the most simple and effective, though the most costly of all. In France as much as 13 to 15 lbs. of the oil per cubic foot is usual as against 12 lbs. in Germany, 10 to 12 lbs. in England, and 10 lbs. in America. The Rueping system aims at moderating the cost of the Bethell process by abstracting a portion of the free oil remaining in the cells of the wood after the withdrawal of the creosote applied under pressure. The zinc-creosote process is very largely used in Germany, and is somewhat similar to the zinc-tannin in its object. The cost of these various methods is dealt with in four Tables, giving that of chemicals, labour, fuel, etc., for different qualities of timber, and under other conditions.

Finally, the plant required is referred to in considerable detail, and an exhaustive article concludes by pointing out the largely-increased stress of traffic in the last decade and its effect on the subject under review. C. O. B.

Preservation of Timber. E. Lemaire.

(Le Génie Civil, Paris, vol. l, pp. 403-6.)

Notwithstanding the fact that the framing of most large structures is now of iron, timber is being used in increasing quantity year by year, and its employment would doubtless be further extended were it not for the rapidity with which it decays. The reasons for this decay are not accurately known, nor is it certain that it is due to extraneous causes, as would at first appear probable from the fact that deterioration takes place from the surface inwards. Of the various substances used as preservatives perhaps creosote has been hitherto the most successful, but it suffers from two serious drawbacks, the one that it adds to the combustibility of timber treated with it, and the other that its smell is so pungent as to preclude its use in confined spaces. In dealing with creosote as a preservative the Author describes three new methods of impregnation, called after the names of their respective inventors—Rütgers, Rueping and Guissani. The

essential feature of the first is that, prior to impregnation, the timber is exposed to the action of steam under pressure with the dual object of softening the fibres and sterilising the material; beyond this the process differs little from that usually employed, except that a small addition of zinc chloride is made to the impregnating-bath. The second and third processes have for their main object the saving in the quantity of creosote used, and in the Rueping process this is effected by first introducing, into the closed vessel containing the timber, air under considerable pressure, the creosote being subsequently forced into the same vessel at a much higher pressure. On this being relieved, the air, imprisoned in the pores of the timber, expands and in doing so drives out the surplus creosote, leaving only sufficient to coat each fibre. The saving in creosote, in the case of soft wood, is said to be 60 to 80 per cent. The Guissani process differs from the Rueping in that no enclosed vessel is required, the timber being first immersed in an open tank containing creosote at a temperature of 140° C., i.e., about 60° C. below its boiling-point, for 1 to 4 hours, after which it is quickly transferred to a second tank containing cold creosote. Voids are produced by this sudden change of temperature and the cold creosote is drawn in. The timber only remains in this bath 3 to 5 minutes when it is placed in a solution of zinc chloride in which it remains 2 to 3 hours. For impregnating with various metallic salts a process due to Mr. Beaumartin is described, the principle of which is that of osmosis produced electrically. Impregnation with molten sulphur is also discussed, it being suggested, that by using sulphur in this state, a combination with the timber is effected somewhat after the nature of vulcanizing as applied to india-rubber.

I. C. B.

Preservation of Mine-Timber. J. M. Nelson.

(Engineering and Mining Journal, New York, 4 May, 1907, p. 839.)

The growing importance of preserving mine-timber from decay is making itself felt in engineering practice. With a view to a saving in the cost of timbering, the Philadelphia-Reading Coal and Iron Company joined with the United States Forest Service to carry out a series of experiments to discover what methods of treatment and handling would give the greatest service at the least expense. Sets of round gangway-timber, principally of pine, were experimented on by three different methods of treatment:—(1) the preservative was heated to a temperature of 180° F. and applied, in two coats, with a brush, creosote (dead oil) and *Avernarius Carbolineum* being the preservative; (2) the timber was immersed in an open tank without pressure in successive baths of hot and cold fluid, in this case the preservatives being a 15-per cent. solution of common salt, a 6-per cent. solution of zinc chloride and creosote; and (3) the timber was treated in a closed cylinder in a vacuum and under

pressure, the zinc-chloride solution and creosote being used. The approximate cost of the treatment worked out as follows, per set of gangway timber of 26 cubic feet:—(1) creosote, 1*s.* 7½*d.*; carbolineum, 4*s.* 7½*d.* (2) common salt, 2*s.*; zinc chloride, 3*s.* 7½*d.*; creosote, 11*s.* 4¾*d.*; (3) zinc chloride, 7*s.* 7½*d.*; creosote, 15*s.* 4¾*d.* The Author gives a diagram showing the increased life of the timber necessary to pay for the cost of these preservative treatments. From this it appears that the increase must be:—(1) 6 per cent. for creosote and 16 per cent. for carbolineum; (2) 7 per cent. for salt, 13 per cent. for zinc chloride and 55 per cent. for creosote. The most successful treatment, economically considered, was with creosote by the second method.

G. G. A.

Economic Size of Pipe for High-pressure Water-power Installations. ARTHUR L. ADAMS, M. Am. Soc. C.E.

(Proceedings, American Society of Civil Engineers, vol. xxxiii, p. 506.)

The most economical size of pipe lies between a very large and consequently costly pipe on the one hand, and a small pipe, in which the friction-losses are high, on the other. The Author bases the solution on the following relation between the investment in any pipe-line and the value of the energy lost in frictional resistances, i.e., that the cost of the pipe, added to the friction-losses expressed in the unit of value, shall be a minimum. The friction-losses are computed by the Chezy formula

$$S = \left(\frac{V}{C\sqrt{R}}\right)^2$$

in which V is the velocity in feet per second, R is the hydraulic radius, C is a coefficient assumed to be 100, and S is the friction-loss in feet per linear foot of pipe. The weight of pipes for given pressures are taken as proportional to the squares of their diameters. The results are given by four curves covering different prices for pipe, and they all point to the conclusion that the pipe which fulfils the requirements of greatest economy is one in which the value of the energy annually lost in frictional resistance is equal to 0·4 of the annual cost of the pipe-line.

R. S. B.

Most Economic Section for Steel and Iron Hydraulic-Pressure Mains. A. ANASTASI.

(Annali della Societa degli Ingegneri e degli Architetti Italiani, Rome, 1906, vol. xxi. pp. 209-22.)

Hydraulic installations for utilizing falls of some magnitude for power purposes consist generally of intake-works, an open feeding-canal and finally an iron or steel pressure-main usually of some consider-

able diameter. In this pressure-main there is usually a considerable variation of hydrostatic pressure, the pipe itself being laid to a steep gradient while the loss of head must necessarily remain small, and hitherto it has been customary to make this main of a constant diameter throughout. The Author here puts forward the suggestion that under these circumstances a constant diameter is not the most economical, and proceeds to the discussion of the following problem:—Given a pressure-main laid to certain lines and gradients and capable of delivering a fixed quantity of water with a given total loss of head, how should the diameter of the main vary throughout its length in order that its total weight may be a minimum?

Taking the general formula giving loss of head per unit-length in terms of quantity and diameter—$h = k\,\frac{Q^m}{d^n}$; and assuming that for all except small pressures, the law connecting pressure, diameter and thickness of pipe is of the form, $t = m\,p\,d$, the Author proceeds to show analytically that for maximum economy the diameter of the pipe should vary inversely as the $(n + 2)^{th}$ root of the hydrostatic pressure, the main being everywhere of equal resistance as regards its thickness. It is proved that under favourable conditions a saving of about 6 per cent. in the weight may be effected thus.

L. F. M.

Draining of Stokke Lake. K. Sommerschield.

(Teknisk Ugeblad, Christiania, 1907, pp. 130–1.)

Jæderen is a tract of flat coast in Norway between Stavanger and Egersund, roughly 25 miles. Until the railway was brought there it was little else than marsh, of which patches from time to time were reclaimed for cultivation. The profit therefrom has at length encouraged the landowners to undertake the draining of Stokke Water, a large shallow lake which lies between two fjords, Hafrsfjord on the west and Gandsfjord on the east. It is about 5 kilometres (3 miles) north of Sandnaes and a little south of Hinna railway station. The natural outflow is into Gandsfjord at Forus, where several mills are driven by the stream. But this is the shallower end of the lake; and it was ultimately decided to drain it from the deeper western end, by tunnelling through the low ridge which separates it from Hafrsfjord. Work was begun in the spring of 1906 by sinking a shaft at the mouth or entrance of the tunnel, and excavating there by blasting an ante-chamber to receive the water from the lake. Pumps in the shaft and a ventilating-fan are worked by a windmill, or by hand when there is not wind enough. The stone is brought up by windlass. Shifts of three men are working night and day. The tunnel will be 330 metres (360 yards) long, 2·5 metres (8¼ feet) wide, 2 metres (6½ feet) high, 1·60

metre (5¼ feet) broad at bottom, with sides sloping 1 in 1½. It is being driven at the rate of 12 to 14 metres (40 to 46 feet) per month, and is thus expected to be finished by the middle of 1908. The rock is mica-slate. The area of the lake is about 1,000 acres, and the surface of the water is 12 metres (39 feet) above sea-level, with a depth of 1½ to 2½ metres (5 to 8 feet). When drained it will present a rich tract for cultivation. The cost is estimated at 80,000 kroner (£4,440), whereof one quarter is contributed by the State; it includes compensation to the mills at Forus. The result is expected to be highly profitable.

A. B.

Experimental Training-Works on the Loire. CH. DANTIN.

(Le Génie Civil, Paris, vol. 1, pp. 225–9.)

Numerous schemes, having for their object the provision of a channel navigable for vessels of light draught between Nantes and Orleans, have been propounded, but nothing of a practical nature was done until 1901, when, on the various bodies interested subscribing among themselves 830,028 francs (£33,200), the Government contributed a like amount, and it was decided to expend the whole in training-works of a more or less experimental nature between the confluence of the Maine and the town of Chalonnes, a length of 14 kilometres (8·75 miles). The bed of the river throughout this length is of sand interspersed with fine gravel, and, as might be expected, the navigable channel repeatedly crosses from side to side, with a marked diminution in depth at such crossings. In many places the stream divides into two or more parts, and as, when this is the case, the minimum depth in the smaller branches is greater than that in the main stream, these have usually been selected for improvement. The works consist in the protection of the bank on the concave side of the various bends and, at suitable points within the straight portions between the bends, the construction of submerged groynes on the opposite side. The groynes are intended to cause silting, and thereby to diminish the width and increase the depth of the navigable channel beside fixing its course. Both the submerged groynes and the protection for the banks are of timber, piles being driven at intervals, and the intervening bays being closed by basket-work hurdles, constructed in the dry, and subsequently nailed to the previously-driven piles. This method of construction is cheap as regards initial outlay, and by its use the raising or lowering, or even total suppression, of any portion already constructed is rendered comparatively simple, a matter of great moment in experimental work. At present it is impossible to express a definite opinion either as to the value of the improvement of the navigation or the durability and sufficiency of the works involved, but as regards the former, two charts are given showing

the river in the neighbourhood of the Lalleud Bridge, the one as it existed before any works were undertaken, and the other two years later. The latter shows a considerable improvement. The difficulty of the work is enhanced by the fact that improvements which may have taken place during normal conditions are sometines entirely destroyed during a single flood.

I. C. B.

Marseilles–Rhône Canal. R. Bonnin.

(La Nature, Paris, 20 April, 1907, pp. 328–30.)

Marseilles, one of the most important ports on the Mediterranean, is only a few miles from the mouth of the Rhône, a navigable river which, in consequence of its connection with the Saône and a vast network of canals, carries a considerable traffic to the centre and the north of France. The growing trade of Genoa, due to the tunnelling of the Simplon and the projected piercing of the Loetschberg, is a serious menace to the interests of Marseilles, and it thus becomes a question of vital importance to construct a canal between Marseilles and the Rhône. This is no new project, since, as far back as 1507, Louis XII had this subject before him. In 1802–35 the canal between Arles and Port-de-Bouc was under construction; but, notwithstanding an expenditure of £600,000, owing to the choice of too shallow a section to admit the vessels navigating the Rhône, the work has been devoid of practical result, and the traffic has been insignificant. In order to avoid the sand-banks which barred the estuary of the Rhône, the maritime canal between St. Louis and the sea was constructed in 1865-70 at a cost of £800,000. By means of this canal it is possible for barges and flats to go from Lyons to Marseilles, but unfortunately when the sea is rough in the Gulf of Foz, which is very often the case, it is impossible for vessels of the inland type to cross it, and therefore the route is not much used. The only satisfactory plan would be to connect Marseilles with the Rhône by a great navigable artery, and this is the scheme adopted by the Chambers in 1903, which is a modification of a previous project put forward in 1893. As now being constructed, the canal starts at Marseilles and is taken along the coast-line near Cape Janet and L'Estaque to the point of the Lave. It then passes through the mountainous range of the Rove by means of a tunnel 4·66 miles in length, from which it emerges at Marignane on the Étang de Bolmon. This tunnel, which will entail an expenditure of about two-fifths of the whole cost of the canal, some £1,160,000, will pass through the rocks of the jurassic and cretaceous periods. The canal then skirts the Étang de Berre as far as Martigues, and enters the Martigues–Port-de-Bouc maritime canal. From this point it strikes directly for Arles, following the old course of the Arles–Port-de-

Bouc canal. It is only in the matter of its junction with the Rhône, which was originally placed at Bras-Mort, and is now removed to Arles, that this scheme differs from that put forward in 1893. There is no doubt that the construction of this canal will render possible the industrial and commercial development of the Étang de Berre, which is at present neglected, and will provide ample space for new factories. The total cost of the undertaking is estimated at £2,840,000, and the depth of water will be 6·56 feet between Arles and Port-de-Bouc and 9·84 feet between Port-de-Bouc and Marseilles.

G. R. R.

Kirkfield Hydraulic Lift-Lock.

(Engineering Record, New York, 30 March, 1907, pp. 415–6.)

This is the fifth lock of this type, there being three in Europe and two in America. It consists of a pair of chambers mounted centrally on the pistons of two hydraulic presses. The chambers, which are of steel 139 feet by 33 feet, are closed at both ends by steel gates connecting the locks with the canal. The power is obtained by making the chambers counter-balance with each other, and by putting into the upper one a greater weight than into the lower, 8¼ inches of depth giving 100 tons of water. When the gates are closed the two presses are connected by a valve, and the greater pressure in the cylinder below the higher chamber forces the water from it into the other cylinder and raises the lower chamber.

The operation of raising a boat, the lift being 48 feet 5 inches, is detailed, and it is stated that the record time occupied at the similar lock at Peterborough, Ontario, where the lift is 65 feet, was 6½ minutes. The foundations on solid-rock, retaining-walls, the breast-wall, which is pierced by two steel aqueducts, the connecting-chambers with upper reach, and the abutments, are of concrete. Details of these are given. The wells for the hydraulic presses 64 feet below the bottom of the lock-pit, the presses themselves, the 170-foot long and 40-foot deep lock-pit adjoining the breast-wall on the lower-reach side cut out of the solid rock, the cantilevers supporting the chambers which carry 1,700 tons of water, the gates and the methods of operating them, and the pumps are interesting features of the work which are described in some detail.

C. O. B.

Sand-Movement on the New South Wales Coast.

G. H. HALLIGAN, Government Hydrographic Officer.

(Proceedings of the Linnean Society of New South Wales, 1906, vol. xxxi, pp. 619–40.)

In this Paper the topography of the coast-line is first referred to, and it is shown that it indicates a very slow negative movement of the land. The effect of this on the outline of the beaches and salient point is compared with the results due to elevation, rapid subsidence or an absence of any movement during recent geological time. A chart of the Pacific Ocean is given, showing the general trend of the ocean-currents round Australia, and from this it is seen that the southerly current on the New South Wales coast is deflected to the east and then to the north, by the powerful E.N.E. current from the Southern Ocean, causing the current south of Sydney to be less powerful and more uncertain than on the coast further north. The effect of this on sand-movement is shown, and diagrams serve to make clear how a projecting headland may cause a counter-current on its northern or southern side, according as its northern side is concave or convex, or whether the headland is at right angles to the course of the current or meets it at an angle.

The beaches between Point Danger and Point Stephens assume a form somewhat like the Greek letter *Zeta*, and the Author refers to this as the characteristic *Zeta* curve, and points out that in all harbour-entrance works, the breakwaters must be carried out far enough to enable this curve to be formed by the moving sand, before the work can be said to be stable.

An analysis of the winds at Sydney and at the Clarence River entrance, over a period of 10 years, shows that north-easters prevail when all winds are considered, but for winds of a higher velocity than 20 miles per hour south-westerlies and south-easterlies predominate, while there are twice as many gales from the south-west as from any other quarter of the compass. The effect of this on the movement of beach-material, and also the effect of waves during flood- and ebb-tide are discussed. The direction of the tidal-wave is almost at right angles to the coast, so that the effect of the tidal-current on the littoral is negligible. A chart of the entire coast shows the currents and counter-currents between Fingall Head and Gabo Island, and a detailed description of each harbour- or river-entrance is given, based on the Author's personal knowledge. The influence of the prevailing and predominant winds on the formation of sand-dunes is mentioned, and instances are cited to show that the southerly winds are the dominant factor in sand-movement above high water, whereas for the movement of beach-material, the littoral-current or counter-currents, accelerated or retarded by the prevailing wind, are alone responsible.

The marked difference in the coastal topography to the south of Sydney, as compared with that to the north, is accounted for by the

retardation and deflection of the southerly steam-current, due to the impact of the more powerful drift-current caused by the "brave west winds" of the Southern Ocean.

C. W. S.

Towing a Floating Dock. Commander F. M. BENNETT, U.S.N.

(Journal of the American Society of Naval Engineers, Washington, 1907, pp. 37–53.)

The Author relates his experience in towing what is known as the "Cavite Dry Dock" between Baltimore and the Philippine Islands viâ the Suez Canal, a distance of 13,089 miles. The dock proved very unmanageable at sea, owing largely, in the Author's opinion, to the fact that the ends were flat, 135 feet wide and 7 feet to 10 feet deep. He suggests that the addition of a temporary pointed bow[1] and a large rudder would have been of considerable value. As it was, the dock frequently "took charge" in rough weather. Three ships, steaming in tandem, towed the dock, and a tug was also in attendance as far as the Suez Canal. The maximum speed attainable was 4½ knots, and repeated breakage of the towing-tackle showed that the limit of its endurance was also a measure of the towing resistance[2] of the dock at that speed. The dock got adrift six times, owing to the following breakages of tackle: a single 6-inch hawser twice; a double 15-inch Manilla hawser once; and once each a 2-inch chain-bridle, a double shackle and a triangular shackle, the two latter of circular section, 3 inches in diameter. Owing to abrasion the timber rubbing-pieces under the 6-inch wire hawsers required constant renewal. Sheathing them with ¼-inch sheet copper materially increased the intervals between the repairs, which, however, were still required weekly.

The ships engaged in towing the dock were as follows:—

	Normal		Towing I.HP.
	I.HP.	Knots.	
"Brutus" (naval collier)	1,200	10	1,100
"Caesar" („ „)	1,500	10	1,200
"Glacier" (supply-ship)	4,000	12½	1,700
Total horse-power	..	..	4,000
"Potomac" (tug)	2,000	16	

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[1] See Minutes of Proceedings Inst. C.E., vol. clxi, pp. 88 and 110.

[2] See "Notes on the Towing-Resistance of a Floating Dock," Minutes of Proceedings Inst. C.E., vol. clxiv, p. 385.

The Paper is accompanied by two plates, giving details of the towing-tackle used. Particulars are also given of the coal burnt during the voyage, which occupied more than 6 months, and of the time and distance between the various ports touched.

C. H. W.

Mannheim "Industrie" Harbour. EISENLOHR.

(Deutsche Bauzeitung, Berlin, 1907, 8 June, pp. 323-5, and 15 June, pp. 333-8.)

The author gives a detailed account of the new "Industrie" harbour at Mannheim, which was formally inaugurated on the 3rd June, 1907. He commences by a historical outline of the growth of Mannheim and its water-borne traffic, which reached 6,950,000 tons in 1905. Great importance is attached to this work, as it is the first instance of a great inland harbour in Germany, built specially for the development of factories by affording them favourable transport facilities. The harbour itself consists of the upstream portion of the old arm of the Rhine, abandoned after the regulation of the Rhine and Neckar at Mannheim. The works have been carried out by the municipality, with State aid, the latter having constructed the entry-locks and the necessary railway communication. The whole harbour-area now capable of development covers over 500 acres, of which about 250 acres are available for factories, etc., and 160 acres are water, excluding the lower portion of the old river-arm which forms the navigable channel to the Rhine. The harbour-embankments have been simply sloped to save expense. They have been constructed in three steps: the lower step 1:1½ with rough-cast stone-pitching up to the ordinary water-levels; the middle step 1:1½ with stone set-pitching; and the upper step 1:2 with grass for the actual flood cross-section. The riparian owners may reconstruct them at their own expense as quay walls if required. Over 6 miles of new roads, all sewered, and 22 miles of main and branch railways have been laid out. The harbour-works were commenced in 1897 and have taken 10 years to complete, at a total cost of £322,500, exclusive of interest on capital. The article is accompanied by plans and illustrations.

F. R. D.

Salina Cruz Harbour Improvements, Mexico.

(Engineering Record, New York, 30 March, 1907, pp. 401-2.)

This harbour claims importance as the Pacific terminus of the Tehuantepec National Railway, which proposes to carry a large portion of the trans-oceanic traffic not only pending the completion of the Panama Canal, but, owing to its more northerly position, competing with it,

when opened, for some of its trade. To do this the most complete arrangements are necessary, and this well-illustrated article gives particulars of these. The new harbour consists of two portions, the outer of two arms 3,240 feet and 2,164 feet, with a 600-foot mouth, and the inner 3,380 feet by 1,210 feet, separated from each other by a quay with a central opening, giving communication between them. The breakwater-arms are of rubble foundation with random blocks and concrete above, and are topped by a monolithic mass of concrete finishing at 18 feet above high water. The quay, 230 feet wide, containing railway-lines, warehouses, electric cranes, electric shunting-capstans, &c., presents the most novel features of construction. Immense monoliths of concrete, 42 feet by 20 feet in plan, were built in situ and sunk to the depth required, each having three wells 8 feet by 10 feet, filled with sand and sealed top and bottom with concrete. These 20-foot thick walls form the face to the inner basin, the outer face being a rubble slope. The sinking and jointing of the monoliths are fully described. A dry dock 624 feet by 100 feet is provided, and extra wharfage by ten jetties on the inner side of the basin is contemplated in the future. Ninety-six out of the 130 acres forming the outer harbour have a minimum depth of 33 feet, which is also the depth of the inner basin. The cost has been $20,000,000 (£4,166,666).

C. O. B.

Whipple Point Beacon.

(Engineering Record, New York, 27 April, 1907, p. 512.)

A remarkable engineering feat in the construction of the Whipple Point Beacon is the subject of a short article. Difficulties, which are fully described, principally due to the high cost of haulage of materials, having arisen, the U.S. Lighthouse Department resolved to wait for the winter, when 5 feet of ice had covered the lake where the beacon was to be erected. The stone required was hauled over the snow to the edge of the bank of the lake on sledges made of timber, one horse under these circumstances doing the work of two in summer. Here the stone was rolled down to the ice, reloaded on similar sledges, and hauled to the site. The crib was built directly on the ice over the spot selected, and continued until a certain weight had been acquired, when the ice around it was cut through and the entire mass allowed to settle. When the bottom of the foundation reached the level of the underside of the solid ice, holes were cut alongside the floating crib, pike-holes were inserted, and the square cake of ice supporting the crib was pushed out from under it and beneath the heavy sheet of solid ice. In order to assist in freeing the cake the crib was heavily weighted on the side opposite to the direction in which the cake was to be pushed, causing the bottom to slant upward so as to facilitate the work.

The construction was then continued until the bed of the lake was reached, the support of the ice around the hole forcing the crib to settle vertically. The total cost, $1,490 (£310 8*s.* 4*d.*), was estimated as one-third to one-half of what it would have been if the work had been done in summer.

C. O. B.

Roller- and Ball-Bearings.

(Railway Age, Chicago, 26 April, 1907, pp. 658–9.)

The undertaking of investigations as to the strength and design of roller- and ball-bearings in connection with rolling-stock is advocated as very necessary. It is noted that owing to the enormous crushing-strength of hard-steel balls and rollers, there is a tendency to take too much advantage of this in determining the minimum number, the fact that elastic failure takes place long before crushing begins being lost sight of. Careful measurement of elastic distortion under varying loads is needed; formulas are then given, and their application to the number and diameters of balls for the centre plate of a 50-ton car, and, incidentally, it is stated as a remarkable fact that $\frac{5}{8}$-inch balls can be tempered more uniformly and reliably than those of any other size. On account of want of uniform temper, which increases with the diameter, small balls are preferable where possible. Conical roller-bearings for turn-tables are then considered, and a formula for the allowable load is given, and rollers for centre plates for cars are dealt with theoretically and practically. The general argument of the article is in favour of investigation in the laboratory, supplemented, but not superseded, by practical tests in service, especially as regards the larger bearings necessary for car-centres.

C. O. B.

Chapsal-Saillot Continuous Air-pressure Brake. CH. DANTIN.

(Le Génie Civil, Paris, vol. 1, pp. 336–8.)

Although within the past 20 years great improvements have been made in the design of locomotives, practically nothing has been done towards eliminating the defects in air-pressure brakes, the two chief of which are (1) the want of a uniform brake-power per ton of gross load and (2) the difficulty of graduating the retarding force. In the brake under review the air-cylinder and the auxiliary storage-receiver are provided as in the case of the Westinghouse apparatus, but the triple valve is replaced by a distributing arrangement of a somewhat different design which admits of the stress on the brake-blocks being always proportional to the difference in pressure between the air in the train-pipe and

in the auxiliary receivers. On the brake being applied, by reducing the pressure in the train-pipe, a small piston drops, and in doing so allows the air in the train-pipe and in the auxiliary receiver to act respectively on two diaphragms, the latter being coupled together. The difference in pressure causes the coupled diaphragms to move, and in doing so they establish communication between the storage-receiver and the brake-cylinder. As the pressure rises in the latter it acts on a third diaphragm which closes the admission-valve when the pressure acting on this diaphragm has advanced to such a point as to overcome the force originally brought into play by the difference in pressure acting on the two diaphragms previously referred to, i.e., between that in the train-pipe and in the storage-receiver. After the brake has been applied, should the pressure in the train-pipe be again allowed to rise, equilibrium would be destroyed and a valve actuated by the same lever as that operating the admission-valve would be opened and would allow the pressure in the brake-cylinder to escape until such time as the reduced pressure acting on the third diaphragm should again establish equilibrium. Thus the difference in pressure between the air in the train-pipe and that in the storage-receivers is always a measure of the force with which the brake-blocks are being applied. The two diaphragms, which are coupled together, act on the admission- and exhaust-valves through the intermediary of a slotted lever, and the position of the fulcrum, within the limits of the slot, is regulated by levers which derive motion from the deflection of the wagon-springs. Thus, with the same pressure in the respective storage-receivers on each wagon, the brakes, when applied, will act more strongly on the loaded than on the light vehicles, and a uniform brake-pressure per ton of gross load can thus be approximated.

I. C. B.

Callipers and the Art of Callipering. Frank A. Stanley.

(American Machinist, New York, 23 March, 1907, pp. 337–62.)

Under this title are collected a series of articles dealing with the workshop methods employed for accurate measurements, and giving complete tables and diagrams of the clearances and tolerances used in various works of repute. In the first article is given a short history of the ordinary calliper, and this is followed by a description of a set of seven large calliper-gauges in use by the Westinghouse Company, which, by means of micrometer adjusting-pieces, have a range of 10 to 40 inches. These gauges are made of aluminium-zinc alloy, and notwithstanding their large size, are very light, so that they can be used by one man, and great delicacy of touch, conducive to accuracy, is obtained. These calliper-gauges are adjusted to any required dimension before taking a measurement by means of an end measuring-rod encased in wood, and combined with a micrometer adjustment-piece. When measuring the diameter

of a shaft the calliper is held in two light swing-chains, and matters are so arranged that the calliper is supported in the same manner as during the previous adjustment, so that any deflection due to its weight is eliminated.

The question of taper force-fits is referred to, and their advantage over parallel force-fits is stated to be that, whereas the latter can only be compared by gauging, the former can be verified by entering the plug into the hole and ascertaining that it stands out a predetermined distance before forcing begins. Thus if the allowance for pressing is 0·01 inch and the taper is 0·005 inch per inch, the plug should stand out 2 inches before pressing home.

An account is given of an important set of trials made at the Alabama Polytechnic Institute to determine, amongst other things, the twisting effort needed to turn the spindle after it has been forced into a disk. The results are exhibited by means of a series of curves, and a numerical example is given illustrating the use of these curves. The practice of several American and English firms in the matter of limits for press- and running-fits, etc., is given in a series of tables and diagrams. Amongst others the "C. W. Hunt limit system" is fully described; the limits to the diameter of shafts, bushings, journals and bearings for close fits, press-fits, loose fits, etc., are based on certain formulas; for instance, for a close fit and for a parallel journal, the formula is, $(0\cdot001\ d + 0\cdot002)$. For several years the Lane and Bodley Company, Cincinnati, have kept records of press-fits; these have been plotted and certain conclusions have been arrived at which are embodied in curves from which the pressure required to force the parts together can be obtained. A numerical example is given, the diameter of the plug being 8 inches, the length of fit 6 inches, the diameter of the nave 16 inches, press-fit allowance 0·020, and by the use of these curves the necessary pressure works out at 78 tons. It is desirable to point out that in the matter of force- and shrink-fits Mr. Moore and Mr. Riddell are not in agreement. A comparative table is given of the allowances made by each, from which it appears that for forcing-fits Mr. Moore's allowance is ten times greater than Mr. Riddell's, whereas for shrink-fits the former's allowance is one-half that of the latter. It is possible that differences in the feed and in the shape of the cutting-tool may be the cause of the discrepancy.

The articles conclude with a short history of the micrometer-gauge, and there is a description of several of the more modern types of them. A method of measuring external screw-thread diameters is given and a somewhat full account of the artifice of inclining the callipers to obtain very accurate measurement. The formula $C = \frac{A^2}{2\,B}$ is deduced, in which A is the side-play of the callipers in sixteenths of an inch, B the dimension (in inches) to which the callipers are set, and C is the difference between the diameter of the piece measured and B in $\frac{1}{1000}$ of an inch.

H. R. S.

40-*Ton Floating Crane.* ADOLF BERAN.

(Zeitschrift des Vereines Deutscher Ingenieure, Berlin, 2 February, 1907, pp. 184–9.)

The increasing trade of Trieste created the necessity for a large crane of this type, and after a careful survey of all the conditions a pontoon-crane of sheer-leg type presenting many interesting features was selected. Special stress was laid on the following points:—(*a*) the pontoon to be as small and, especially, as short as possible, in order to meet the exigencies of a rather narrow harbour; (*b*) great ease in manœuvring to be possible in view of the congested state of the harbour; (*c*) a speed of three knots to be attainable to enable the crane to be quickly moved to the new harbour-works now in progress. The pontoon was divided into three watertight compartments, and was provided with special water-ballast tanks in the stern. All steam-engines, pumps, winches, etc., were constructed to act condensing, and the winding-gear on trial gave speeds of 1·7 metre (5·58 feet) per minute for a load of 40 tons and 7·5 metres (24·6 feet) per minute for a load of 10 tons. About 5½ minutes were specified for raising the sheer-legs from the outboard to the inboard position. The maximum loads were 40 tons at 6 metres (19·7 feet) overhang, and 25 tons at 10 metres (32·8 feet) overhang. The article is accompanied by a number of illustrations and diagrams.

C. J. G.

Tests of Motor-Car Engines. FEHRMANN.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, Berlin, 1907, pp. 107–200.)

The Author reports on a series of experiments and tests, carried out on nine different types of cars and engines of six makers, in order (1) to determine the coefficient of efficiency of different forms of gearing, and (2) to investigate the values of benzol and alcohol, alone, in combination, and in combination with benzine, as fuels for internal-combustion engines. Full details of the engines and gearing-constructions are given. The nominal HP. of the motors was 28 to 4 HP. The load-tests were carried out by means of a water-cooled Prony brake, and the fuel-tests by specially designed weighing-balance. The fuels consisted of benzine of 0·705 specific gravity at 59° F., with 18,600 B.Th.U. per pound, benzol of 0·881 specific gravity and 16,800 B.Th.U. per pound, and, lastly, alcohol (86 per cent.) of 9,600 to 101,000 B.Th.U. per pound. The fuels were mixed in given varying proportions; the benzine, however, only absorbed 10 to 20 per cent. of the alcohol.

The results of the fuel tests may be summarized as follows:—

1. The motors, which were designed with efficient means of warming the air for combustion and for properly proportioning the

charge of the air and fuel gave similar maximum efficiency for benzine, benzol and alcohol, and when inefficient, benzol gave results 4 to 8 per cent., and alcohol 16 to 19 per cent. below the benzine maximum efficiency. The mixed fuels gave results between the above figures.

2. Benzol and benzine showed equal heat-efficiency under all loads, whereas the alcohol gave invariably better results on the high loads and always worse on the low loads.

3. These differences are probably due to false proportions of air and fuel.

4. On the assumption that ignition was properly regulated in every case, the better efficiencies obtained from benzine and benzol in comparison to the alcohol-tests were due to the higher explosive-charges of the mixtures.

5. Disregarding its stability at low temperatures benzol offers no difficulties for high-speed motors when a proper mixture of fuel and air is provided. An insufficient air-supply, however, causes immediate stoppage.

The article is accompanied by drawings and detailed tables of the tests.

F. R. D.

Superheated Steam. R. P. Bolton.

(Engineering Magazine, New York and London, March, 1907, pp. 875–82.)

In the first of three articles, the others following in immediate sequence, the Author treats exhaustively the influence and limitations of superheat, beginning with a historical summary and a glance into physical laws governing the addition of heat to steam-vapour or gas. Under the headings of specific heat, moisture, early troubles, steam-jackets and reheaters, and cylinder-work, the article gives the most important recent tests and experiments, and the general relations of superheating to economy in the steam cylinder.

In the second article, American and European practice in this matter are contrasted, and reasons are suggested for the hesitation of the former to follow entirely the lead of Europe, where there are more enthusiastic advocates of high-temperature superheat. Heating buildings, steam-piping, joints, waterworks-engines, and turbines, in the development of which superheated steam has played a most important part, are fully dealt with in this connection.

The third article will deal generally with locomotive and marine practice, and will contain a bibliography.

The Editors promise to supplement this series with one on fuel-combustion in the boiler-furnace, by W. D. Ennis.

C. O. B.

Compressing Air by Falling Water. J. H. Hart.

(Engineering and Mining Journal, New York, 4 May, 1907, p. 855.)

The use of compressed air in mining operations has become so general that any improvement in the means for its production is eagerly adopted by engineers. The ordinary compressor wastes more than 40 per cent. of its energy in the machine alone. Yet there is a method of compressing air that is far more efficient, extremely simple, isothermal, and practical. This is the water-compression system. It is strange that this system, in successful operation in many places in the United States, is not more widely known and adopted. The burden of patent rights may be one cause of its lack of quick development, but as these plants produce compressed-air in large quantities very efficiently and very cheaply, at a very low cost of installation, this objection has but little force.

The process, simple in theory and in practice, is extremely ingenious. Water is conveyed in a large pipe on a slight slope to the edge of a vertical pipe set in a hole of any desired depth. Down this pipe the water is allowed to fall. A hollow ring, having a large number of small holes on its lower side, is immersed in the water at its entrance into this pipe; and the hollow is in communication through a pipe with the outside air. The water flowing past these small holes, which are often extended into projecting hollow needles for increased efficiency, entangles and carries with it small bubbles of air caught at the points of these needles. As it falls down the pipe, it gradually compresses the bubbles. If at the bottom the water is suddenly turned into a fairly large reservoir, it comes to rest and the bubbles rise to the surface under pressure. A pipe carries the water from this reservoir back to the surface. The difference of level of the inflowing and outflowing water need be only a few feet to give a rapid flow. The pressure obtained depends simply on the depth of the hole, that is, the length of the vertical pipe down which the water falls. The pipes are so arranged that the inflow-pipe is outside the outflow-conduit, so that only one hole is required. The reservoir at the bottom is merely an enlargement of the hole, and it is usually lined with metal. Air under pressure collects in this reservoir, from which it may be drawn for use through a pipe to the surface as required. The plant needs no attention. The efficiency ranges between 75 and 83 per cent. The Author gives a diagrammatic section to show the construction of such a plant.

G. G. A.

Starrett Air-Lift Pump.

(Engineering and Mining Journal, New York, 30 March, 1907, p. 611.)

The Starrett pump is designed on a new principle of action, or rather on a novel combination of two old principles. The fact that it has been brought into use for mining purposes is evidence of satisfactory working in practice. One of these pumps is now working at the Ward shaft on the Comstock Lode, Nevada, where, with an air-pressure of 50 lbs. to the square inch, it lifts 300 gallons of water per minute to a height of 250 feet. In the Starrett design the water is first lifted by the direct pressure of the compressed air : then, when a head of water equal in weight to the air-pressure has been forced up the discharge-pipe, the compressed-air is introduced into the discharge-column near the lower end, reducing the weight and causing a second upward-flow by the well-known principle of air-bubble expansion. The working of the pump is very simple. Suppose an air-pressure of 20 lbs. Air at that pressure in the pump-cylinder will force 40 feet of water through the check-valve in the lower end of the discharge-pipe. When equilibrium is established, the air at 20 lbs. is let into the water-column at some distance above the water-inlet valve. The weight of the water in the discharge-pipe at this point is less than at the inlet-valve. The jet of air then forces, or lifts, the column of water to the overflow. The moment an overflow occurs from the discharge-pipe, the weight on the check-valve is reduced, and the exact quantity of water to compensate the overflow enters the column. Thus the pump can never over-load itself, the flow of water into the discharge-pipe being automatically regulated by the air-pressure. Instead of raising a heavy load slowly the pump lifts light loads in rapid succession, the quantity of water discharged depending on pressure and the quantity of air used. With a double pump, i.e. one having two chambers or cylinders, the water is made to flow in a continuous stream by means of a device called a "shifter." This shifter automatically turns the air from one cylinder into the other, there being then no apparent break in the discharge-column of water. The shifter-piston has a travel of only 1 inch. The cost for repairs is small, for there are no rings, packing, lining, piston or rods. It requires no lubrication and needs but little attention. As there is no vibration, no foundations are required. It works effectively when suspended by chains immersed in the water. The efficiency is said to be 50 per cent. at the compressor, the net efficiency being 35 per cent.

G. G. A.

Mining in the Clausthal District. H. Schennen.

(Glückauf, Essen, 1907, vol. xliii, p. 657.)

During the past 5 years notable improvements have been made in the methods of winding, of ore-dressing and of power-production at the mines in the district of Clausthal in the Harz. Formerly the ores were raised to the Ernst August adit level, and conveyed by boat to the Ottiliae shaft, in which they were raised to the dressing-floor. Owing to the increasing depth of the mines this method became costly. The deepest water-level, 754 feet below the Ernst August adit and 1,869 feet below the surface, was consequently converted into a main haulage-level, the ores being hauled by an electric locomotive and raised in the Ottiliae shaft, which has been deepened for the purpose. A new blind shaft, the Thekla, has been sunk from the water-level, and equipped with electric winding-plant. At the Ottiliae shaft electric winding-plant on the Koepe system has been installed.

The new central ore-dressing plant has been designed for an output of 360 tons in 10 hours. The ores treated consist of 4·17 to 10·34 per cent. of galena, 0 to 20·95 per cent. of zinc blende, and 0 to 0·23 per cent. of copper pyrites, the lodestuff consisting of fluor-spar, calcite, quartz, mica schist, clay-slate and spathic iron ore. In spite of the similarity in composition of the ores from the various mines, differences in structure prevent them from being treated together. Storage-bins are consequently arranged for the ores from each mine. For fine crushing to 2·5 millimetres rolls are used, and below that size pendulum-mills. The crushing- and jigging-machines are in the main building, and in a second building communicating with it the slime-washing plant is installed. In front of the second building the centrifugal pumps, for pumping back the water from the settling-ponds, are placed under cover, and the electric motors for driving the machinery are in another house near the shaft. The buildings, which are of sufficient height to permit of continuous working, are built of ironwork and artificial sandstone. They cover an area of 63,280 square feet, and are heated by steam and lighted by electricity. Great care is exercised in the selection of the apparatus for the treatment of slimes. For the coarser size, Humboldt's shaking-tables, a modification of the Wilfley concentrator, are used; and for the finest sizes Harz circular tables, the rotating-table being made of cement, and the feed being stationary. The whole plant requires 4,400 gallons of water per minute, and the power required consists of six continuous-current motors, each of 210 HP. for the machinery in the main building, one 70-HP. motor for the washing-floor, and one 100-HP. motor for driving each of the centrifugal pumps. The power is generated in two central stations. In one there are two turbines, and in the other four gas-engines and three turbines. The saving in cost due to the improvements introduced has been considerable. In 1897–98 the cost of winding and transporting by boat 1 cubic metre of ore

was 1·6154 mark ($1\frac{3}{5}$*s.*); in 1905–06 the cost of winding and hauling the same amount of ore was 0·7788 mark ($\frac{4}{5}$*s.*), representing a saving of 0·8366 mark ($\frac{4}{5}$*s.*). The cost of winding the ore in the Ottiliae shaft was 1·1886 mark ($1\frac{1}{5}$*s.*) in 1897–98, and 0·4366 mark ($\frac{2}{5}$*s.*) in 1905–06, a decrease of 0·7520 mark ($\frac{4}{5}$*s.*). At the old ore-dressing plant 450 men were employed. The new works require only 200 men.

B. H. B.

Conveyor System for Coal-getting. F. W. Parsons.

(Engineering and Mining Journal, New York, 18 May, 1907, p. 958.)

Among recent developments in coal-mining that of the application of the conveyor system to the working of thin seams is especially worthy of note. Seams that would not pay to work by the old method of ripping down the roof to make headway for the tubs, may become fairly profitable when conveyors are used to carry the coal from the face to the nearest haulage-way. These conveyors can be driven by either compressed air or electricity. Experience hitherto is in favour of compressed air, as being more simple to manage in the hands of untrained men. The best example of this underground conveyor-system in America is probably that installed at the Vintondale colliery in Pennsylvania. The system has been in use there for several years, and has greatly reduced the cost of production, making profitable the working of seams which could not otherwise have paid the cost of production.

The conveyor here used is of the pan type, 12 inches wide at the bottom, 18 inches wide at the top, and 6 inches deep. In the pan is run a drag-chain, passing over a sprocket-wheel at the head-end, which does the driving and returns over another sprocket at the rear-end. Both front- and rear-ends are inclined; at the front to obtain height enough to allow the mine-trucks to pass under, and at the rear-end to give height for the sprocket-wheel. The conveyors are driven by a small double-cylinder air-engine. The engine and gearing are mounted on a frame separate from the conveyor proper, power being transmitted by means of a steel roller-chain to a sprocket-wheel on the driving-shaft of the conveyor. Compressed air for driving the conveyor and the undercutting-machine is brought up to the working-face in a 2-inch pipe from the heading above. Connection with this pipe is made by means of a 10-foot length of $2\frac{1}{2}$-inch wire-bound hose attached to a second pipe which runs the entire length of the face. This pipe has outlets with 2-inch stop-cocks at intervals of 48 feet, to which the hose from the coal-cutters may be attached. To shift the conveyor as the coal-face is worked away takes about 20 minutes. The record of one mine for the last 3 years shows a saving of 48 per cent. in cost over the method previously followed.

G. G. A.

Saarbrücken Collieries of the Prussian Government.

FRIEDRICH OKORN.

(Berg- und Hüttenmännisches Jahrbuch der k.k. montanistischen Hochschulen Vienna, 1907, vol. lv, p. 1.)

In a monograph covering 80 pages, the Author describes the geology of the Saarbrücken coal-field and gives particulars of the methods of mining adopted at the collieries belonging to the Prussian government. At this important coal-field the government collieries produce 10 million tons of coal annually; and down to a depth of 3,000 feet there are 3,660 million tons still available in the government coal-field. The deepest shaft at the present time is that of the Luisental colliery, which is 2,240 feet in depth. The working of the seams in most cases is effected by a filling-up method. Of the 10,295,100 tons of coal raised in 1904, only 9 per cent. was obtained by pillar and stall workings without the empty spaces being filled up with rubbish. The advantages claimed for the stowing method of working are less loss of coal, simplicity of ventilation, less danger from falls of rock and coal, and no appreciable surface-subsidence. Three quarters of the waste required for stowing (3,308,600 tons) is obtained on the spot. The remainder is brought from other parts of the colliery (45,560 tons), from the surface (45,560 tons), or is carried down by a flushing system (34,200 tons). The introduction of the stowing method of working and of systematic timbering has greatly lessened the risk of falls of roof and side. Whilst in 1892–96 accidents of that kind were fatal to the extent of 1·54 per 1000 men employed, the proportion was reduced to 0·61 per 1000 in 1904. In view of the fact that much of the surface of the government coal-field is thickly built over, the flushing method of stowing recently introduced in other districts is coming into increasing use. The waste from the washeries, broken boiler-clinker, material from the spoil-banks and sand from local deposits are carried down into the mine by a current of water in steel or cast-iron pipes and allowed to settle. Experiments carried out at the Altenwald colliery have shown that steel pipes must be changed or turned over when 74,500 cubic metres of waste from the washeries, or 43,200 cubic metres of sand have been flushed through them. With cast-iron pipes this is necessary after the flushing through of 52,000 cubic metres of waste from the washeries, or 45,800 cubic metres of sand. The steel pipes have a thickness of 8 millimetres and an internal diameter of 185 millimetres. The cast-iron pipes have a thickness of 10 millimetres and an internal diameter of 150 millimetres. With the introduction of the flushing method, the longwall system of working is coming into more extensive use, it being the most suitable for the purpose. The total cost of working with the flushing method is not appreciably higher than with stowing by hand, whilst the saving in timber is considerable and there is no risk of mine fires. Special precautions for avoiding such disasters are therefore unneces-

sary. Nevertheless all the mine officials and a corresponding number of the workmen are trained in the use of rescue appliances. The equipment comprises 41 Dräger apparatus, 28 Giersberg apparatus, 29 Walcher-Gärtner apparatus, 12 Neupert pneumatophores and 36 smoke-masks of various types, together with 170 electric accumulator-lamps. In the year 1905–6 the total production of the government collieries was 10,787,793 tons; the number of workmen employed, not including officials, was 46,232; the number of working-days 299·9; the daily output per man 0·778 ton; and the colliery coal-consumption was 1,390,747 tons, or 12·9 per cent. of the output.

B. H. B.

Coal in the Sahara Desert. AD. CARNOT.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Paris, March, 1907, pp. 229–33.)

This is a report on a memoir by Mr. E. F. Gautier on explorations carried out by him to the south of Algeria in order to demonstrate the existence of coal in the Sahara Desert. Mr. Gautier states that, like previous explorers in this district, he has found no coal-beds, nor, in fact, any trace of actual coal; but he traversed a wide tract of carboniferous formations between Figuig and In-Salah, extending over an area of some 500 miles in length, throughout which he encountered in numerous places characteristic evidences of these formations, and obtained typical fossils from some fifteen different localities. By reference to maps he explains the geological conformation in the region of Béchar contiguous to Algeria and traversed by the Beni-Ounif–Igli Railway. This country has lately been surveyed by Lieut. Poirmeur, and contains five prominent mountain ranges. A second memoir by Mr. Gautier relates to the vast territory between the south-east of Figuig and the Djebel-Béchar and beyond In-R'ar and In-Salah. This country, which he likewise explored, is rich in the remains of the Devonian period and of the Dinantian era. Though his results were on the whole unsatisfactory in that he failed to find coal, he is sanguine that coal-beds probably exist under the vast cretaceous plateaus or under the sands of the Great Erg.

G. R. R.

Sinking of the Adolf Pit, Upper Silesia. BODART.

(Revue Universelle des Mines, Liége and Paris, 1907, 4th ser., vol. xvii, p. 217.)

This is an abstract of a long memoir which has appeared in a German mining journal in Upper Silesia, describing the difficulties encountered in sinking a colliery-shaft near Mikultschütz, in Upper Silesia, by the Donnersmarck Hütte Company. The depth to the

coal measures is 200 metres, made up of 6 metres of drift-sand and clay at the top, 161 metres of alternating dolomites and limestones, and 20 metres of variegated sands, clays and sandstones at the bottom, resting on coal-measure shales. The sinking commenced on the 23rd October, 1901, was carried on by hand to the depth of 183·7 metres, with several long interruptions, caused by the influx of water from a series of open fissures encountered in the dolomitic rocks, notably between 50 and 60 metres, and 101 and 120 metres, which were only overcome by the use of an unusually large pumping power. Originally two Schwade sinking pumps, each delivering 2½ tons per minute at 150 metres lift, and a horizontal duplex pump of the same capacity were provided, and to these were subsequently added two other sinking pumps of larger capacity; but their combined action was insufficient to master the feeder at 109 metres, which amounted to 8½ tons per minute, beyond keeping the water in the pit down to the 73-metre level, with a coal consumption of 35 tons per day, which had to be carted over bad country roads, the sinking being without railway connections. It was therefore resolved to make a complete change, giving up the use of steam and taking to electric power derived from the Donnersmarck Ironworks, about 2½ miles distant, where there is a large electric generating-station driven by blast-furnace gas-engines, and substituting centrifugal for reciprocating pumps. For this purpose six sets of centrifugal pumps by Messrs. Sulzer Brothers, with motors by Messrs. Brown, Boveri & Co., were provided, three being of horizontal and three of vertical construction. The former, placed in a chamber at 70 metres depth, are intended to supply the water necessary for the surface works and include two of two stages of 130 HP. each, lifting 4 tons 90 metres per minute, and a third of three stages, of 8 tons capacity and 160 metres lift, requiring 400 HP. The three vertical pumps are mounted on suspension frames for use as sinking lifts. Each has three stage combinations driven by a 400-HP. motor, with a capacity of 8 tons per minute under 160 metres head, at 1,000 revolutions per minute.

The total weight of the pump when mounted and at work is about 42 tons. The suspension frame is 35½ feet high, but the surface covered in the pit, a rectangle of 6½ feet by 3½ feet, is less than that of a steam pump of only 2½ tons lifting power. The power, about 2,000 HP., generated at the works at 1,000 volts, is raised to 10,000 volts for the land-line for transmission to the pit, where it is reduced to the original voltage by a 250-kilowatt transformer, which is supplemented by a starting transformer giving current at 330 volts. Many difficulties were encountered at first, on account of the variable demand, affecting the regularity of the working of the central station, but these were overcome principally by the addition of a new 1,000-HP. generator to the station and the raising of the voltage of the starting transformer to 500 volts, when the pump ran without accident for a period of 7½ months, during which time the pit was sunk and lined 55 metres under a flow of 14 tons of water per minute.

For passing through the sandy strata below the limestones the method of pressing down a column of tubbing with a cutting-shoe at the bottom was adopted successfully until 183–7 metres was reached, when an irruption of sandy water overcame the pumps, choking the windbores and suction-pipes with sand, and a series of large open fissures were discovered in the ground adjacent to the shaft. It became necessary, therefore, to adopt the method of boring under water to complete the remaining 13 feet to the coal measures; the fissures being first filled with gravel, and holes bored in the tubbing at 172 metres to prevent the water working round underneath the cutting-edge of the shoe. The progress was, however, very slow, and a diver was employed who found that the shoe was resting at several points on blocks of sandstone and conglomerate, which prevented its descent. To remove these a disintegrator, consisting of a jet-pipe with a water-supply at 18 atmospheres pressure, was used, which was worked round the lower edge of the shoe by a hooked guide manipulated by the diver, but in 10 weeks the depth was only increased by 4 metres. It was therefore decided to plug the bottom of the sinking with concrete, which was done to a thickness of about 10 feet, and the fissures behind the tubbing were injected with concrete, about 1,500 tons of concrete, made of equal parts of sand and cement, being required to form a compact monolith about the shaft. The bottom plug, when hardened, was traversed by cutting it away in a ring, leaving a solid central pillar, against which the tubbing rigs were supported by diagonal timber struts until the solid coal-measure ground below was reached. Of the total depth of 200 metres about 23 metres are lined with cast-iron tubbing alone, and the remainder with masonry, with an inside tubbing, over about 42 metres, through the principal fissures. A portion of the heavy feeder encountered at 120 metres has been trapped, and rises by its own pressure, through a 16-inch pipe imbedded in the rock

Period.	Days' Work on			Total.	Depth	
	Sinking and Walling.	Repairs.	Stoppages.	Working-Days.	Sunk.	Lined.
					Metres.	Metres.
23 October, 1901 – 22 „ 1902	198	47·0	55	300	109	73
23 „ 1902 – 22 „ 1903	..	46·0	255	301	..	..
23 „ 1903 – 22 „ 1904	198	11·9	13	330	78	114
23 „ 1904 – 8 April, 1905 .	136	11·0	..	147	13	13
Total . .	532	115·9	323	1,078	200	200
Per cent. .	49·3	20·7	30	..	..	..

behind the shaft-lining, to the pump-chamber, at 70 metres, to augment the surface-supply. It is a noticeable circumstance that, in spite of the difficulties encountered, the pit has been kept the diameter of 5·1 metres (16¾ feet), as originally planned, throughout. The work has occupied 3½ years, including all stoppages for repairs and other causes, as shown in the Table on p. 448.

H. B.

Frozen Shaft-Sinking in Lorraine. JUNGST.

(Glückauf, Essen, 1907, p. 625.)

At Klein Rosseln, near Forbach in Lorraine, the sinking of two pits for a new colliery has been undertaken for Messrs. de Wendel by the Entreprise Générale of Paris and the Hanover Deep Boring Company. It is intended to raise 4,000 tons of coal daily in two shifts, the whole of which is to be drawn in the No. 1 downcast shaft, No. 2 being reserved for travelling, lowering timber and supplies, and as upcast for the ventilation. As there had been previous failures in sinking undertaken in the district, both with sinking pumps and the Kind-Chaudron method, it was decided to use the Poetsch freezing process in sinking the pits. The strata covering the coal measures—principally sandstones and conglomerates—belonging to the Trias and Permian formations, are 153½ metres thick, but as the trial borings gave indications of a possible fault at that depth it was decided to carry the freezing bore-holes some depth into the older formation, making the total depth of the frozen ground 187 metres (613½ feet) below the surface. An advance pit 10 metres in diameter, secured by a temporary iron lining, was sunk by hand through the surface ground down to 25 metres, where the borings for the freezing tubes were commenced. These are twenty-seven in number, arranged at equal intervals on the circumference of a circle 7·3 metres (24 feet) in diameter. Two of them were bored with a diamond drill in order to obtain information as to the ground suitable for the seating of the tubbing, and the remainder by a free falling percussive method. The verticality of the holes was tested by a plumb-line apparatus at intervals of 10 metres, and the greatest deviation was found to be about 26 inches in No. 27 hole and the least 1½ inch in No. 23. With very few exceptions the deviation of the holes was towards the centre, so that the effect may be considered as beneficial rather than otherwise. The whole of the borings were completed in 8¾ months. The circulating pipes for the freezing fluid, 35 millimetres wide for the supply and 110 millimetres for the return, had a total length of 4,400 metres (2·6 miles) with a cooling surface of 1,520 square metres (16,360 square feet) giving a heat-abstracting capacity of about 300,000 calories per hour. The ammonia-compressor is driven by a single-cylinder condensing-engine of 300 millimetres diameter and 650 millimetres stroke, making 80 revolutions per minute. The cooling-worms in the ammonia-

condensers have a total length of 1,200 metres, with 130 square metres surface, and 12 cwts. of anhydrous liquid ammonia formed the initial filling. The evaporating coil in the cooling tank is 1,460 metres long with 155 square metres surface. The total volume of the cooling fluid, a 10 per cent. chloride of calcium solution of specific heat 0·86, is 78,000 litres, which is circulated through the system at the rate of 80 cubic metres per hour. The freezing process was completed in 2¾ months, during which time preparations were made for carrying out the sinking by hand in the usual way, with the assistance of a Tomson safety-ladder arrangement for the sinkers and a suspended trolley-platform. The bottom crib of the tubbing was placed at 191 metres, and four lengths of tubbing, together 164 metres, have been erected; the upper length of 37 metres above the water-level has been lined with masonry. The frozen ground was sufficiently hard to allow the use of a provisional lining to be dispensed with, and the whole work was accomplished in 11⅓ months, giving an average of 14·65 metres per month of a shaft 19 feet diameter inside and 22 feet in the excavated ground. Inclusive of the time required for boring and freezing ground, the rate of working has been 6·4 metres per month. In the sinking of the second shaft the boring has only been commenced at the water-level, 40 metres down, which dispenses with about 400 metres of boring and 15 metres in the depth of frozen ground. The addition of soda or other substances to the water used in mixing the concrete for the backing of the tubbing has not been found to be of any use, and it is considered better to use plain water and, in the event of its freezing, to await the thawing of the ground, when the concrete is found to set in the regular way. The principal seam in the district has been cut in the No. 1 shaft with a thickness of 8 metres and a dip of 37°.

H. B.

Photographing Walls of Bore-holes. J. T. Atwood.

(Engineering and Mining Journal, New York, 18 May, 1907, p. 944.)

The need for ascertaining accurately the nature and character of the strata passed through in a deep boring for exploring purposes has been very effectually met by the application of photography to the solution of the problem. The possibility of producing a continuous photographic picture of the walls of a boring has been realized in the specially-constructed camera, described and illustrated by the Author. This camera, 32 inches long and 3$\frac{3}{16}$ by 1⅝ inches in cross section, is mounted in the lower end of an iron water-tight tube 43 inches long and 5 inches in outside diameter. It is fitted with a 9-inch Bausch and Lomb rectilinear lens, and is so placed in the tube as to photograph 4½ inches of wall on 3⅝ inches of film, the greatest length obtainable with a width of film of only 1¼ inch. This gives a picture eight-tenths full size. Near the upper end of the tube is a plate-glass window with a mirror at the back of it

so mounted as to reflect the image of an object before the window directly down the tube and into the camera. On each side of the mirror there is a 10-volt, 5-candle-power electric lamp, the light from which is thrown through the window by a reflector, which also prevents any light from falling directly into the camera. The latter is fixed in the tube by two thumb-screws. The film is wound from the end roll across the flat plate where the exposure is made on to the other roll by the action of an electro-magnet on a pawl- and ratchet-wheel. The camera-tube is suspended in the bore-hole on a twisted wire-cord from a drum on a tripod at the surface, electric connection being made through a cable wound on a second drum with a battery of small storage cells. The suspension-cord is so fastened to the tube that the window will come close to the wall of an ordinary 6-inch bore-hole.

In making an exposure, the lights are turned on for about 20 seconds. Before making a second exposure, the camera-tube is raised or lowered 4½ inches, the distance covered by one photograph, and a new portion of the film is brought into position by making and breaking the circuit of the electro-magnet. In this way a series of fifty or more photographs can be taken at the rate of one a minute, and they will show a continuous length of the wall for a distance of about 20 feet. There is no difficulty in getting good photographs under water, provided the precaution be taken of drying the air in the camera by forcing it through sulphuric acid to prevent the deposition of moisture on the window-glass. Photographs obtained by this means give exact information concerning the rock passed through which can be arrived at in no other way.

G. G. A.

Explosives Testing-Station.

(Engineering and Mining Journal, New York, 25 May, 1907, p. 1006.)

The United States Geological Survey have an Explosives Testing-Station nearing completion in the Pittsburg coal-mining district. It is modelled mainly on the Government Testing-Station at Woolwich, but it possesses features suggested by recent experience which will bring the system of explosive-testing up to date. The "gallery" made of boiler-plate, is in the form of a cylinder 100 feet long and 6 feet in diameter. Along the top there is a series of safety-valves on hinges to allow the escape of the gases after an explosion. Port-holes along the sides, covered with ½-inch plate-glass, allow the experimenters in the observation-house to see whether or not an explosion has taken place in the gallery when the trial-shot is fired. The cylinder will be filled with a highly explosive mixture of fire-damp and air, or of coal-dust and air, and into this mixture the explosive on trial will be fired from a steel mortar by electricity from the observation-house parallel to the

gallery 60 feet distant. The fire-damp and air will be thoroughly mixed by an electric fan.

Two preliminary tests of the explosives will be made to determine the quantity required to produce a given disruptive effect; one with the heavy pendulum, as used at Woolwich; the other with the well-known Trauzl block. Further, a pressure-gauge will be used to record the pressure in pounds to the square inch developed by the detonation of the various explosives. An analysis of the products of combustion will be made, and the heat of decomposition, in terms of calories, will be ascertained by detonating large quantities of the explosive in a bomb. Also the explosives will be fired from the mortar at night, when the length of the flame will be recorded by photography, and the time of the flame determined by a special electrical apparatus. Finally, the rate of explosion will be ascertained by means of an electrical rotating recording-drum. Besides these experiments, actual trials will be made in the mine to ascertain the amount of slack made by the various explosives, and to disclose any difficulties in the practical handling of them. A classification can then be made with reference to the cost of explosives per ton of round coal got. The explosives which pass the gallery tests will be tabulated as "Permissible Explosives," and the maximum quantity of each to be fired with safety will be published with the Official List.

G. G. A.

Lining of Galleries by Reinforced Concrete in the Bethune Mines.

(Le Génie Civil, Paris, vol. li, pp. 97–8.)

Owing to the scarcity of masons the Bethune Mining Company decided in 1904 to experiment with reinforced concrete as a material for lining the galleries of the mines, in place of masonry side-walls, of ½ metre (20 inches) in thickness supporting rolled joists carrying the roof. The experiments were so successful that further work was undertaken, and at the end of 1906, 2·306 kilometres (1·43 mile) of way under the control of this company were lined with reinforced concrete. The lining is carried out in lengths of 5 metres (16·4 feet), four frames or centres being used for each length. In section the lining has an arched top and the side-walls are made with a curved batter. The frames or centres are so constructed that they can be readily withdrawn, and, to allow for irregularities of the floor, the lower ends of the side uprights are capable of being lengthened or shortened by means of a sliding arrangement. The reinforcement consists of iron bars 10 millimetres (0·4 inch) square spaced 0·8 metre (2·62 feet) apart and extending circumferentially round the sides and roof of the gallery at a distance of 0·075 metre (3 inches) outside the face of the frames; the exact position both as regards spacing and distance from frames,

and consequently from the face of the finished work, being fixed by grooves in four battens attached to the side frames and extending from end to end of the length in course of construction. The concrete consists of equal parts of lime-mortar and of burnt shale, the latter in pieces of 5 to 40 millimetres (0·2 to 1·6 inch) diameter. For the side-walls nothing else is used, but for the arch Portland cement is added in such quantity as the dampness of the surroundings seems to warrant. In very bad ground recourse is had to injection of Portland-cement grout after the concrete has been rammed in as solidly as possible. The total cost of lining galleries of a section of 2·9 by 2·6 metres (9·51 by 8·53 feet) is given as 26·24 francs per lineal metre (19*s.* 1*d.* per lineal yard), a saving of about 40 per cent. over the former method. In addition to the cheaper cost the following advantages are claimed as compared with the system previously employed:—(1) Increase in strength, the concrete becoming harder through lapse of time; (2) less obstruction to air-circulation; (3) absence of cavities within which coal-dust may lodge; (4) rapidity of execution.

I. C. B.

Koepe System of Winding. S. Meulen.

(Bulletin de la Société de l'Industrie Minérale de St. Etienne, 1907, 4 ser., vol. vi, p. 365.

This is a discussion of the working of a Koepe winding-engine at Marles in the north of France, where it has been in use for 14 years in a pit 311 metres deep. The arrangements are somewhat old-fashioned, and unfavourable to the proper development of the method, the pit frame being only 15 metres high; the guide pulleys, which are only 3·30 metres in diameter, are placed at the same level, but make an angle of 2° 30′ with each other in plan. The winding-disk is 7 metres in diameter. The grooved rim for the winding-rope was originally lined with a wood packing which lasted about a year. Afterwards bronze rings were substituted, which last longer; in one case the same has been in use for more than 5 years, while another has not worn so well. The removal and renewal of the packing can be done in 15 to 18 hours. The new winding-rope is 54 millimetres in diameter, with a minimum guaranteed breaking-stress of 130 tons. The length for the depth of 311 metres is 405 metres, and the weight per metre 9·925 kilograms (6·66 lbs. per lineal foot). The first ropes were made of galvanized wire, but gave very unequal results, varying between 18 months with the best and less than 4 months with the worst. Latterly bright steel ropes have been tried; the first gave a very poor result, while the second seems to promise better. The tail-rope is of the same weight as the winding-rope but of a flat section. The cages are four-decked, each carrying two tubs with a load of 10 cwts., or a total net load of 4 tons. The cage weighs 5·850 tons, the eight empty tubs 2 tons, and the ropes and their attachments 3·574 tons, giving a total weight of

15·424 tons for the loaded and 11·424 tons for the empty cage-side. The length of the rope is so regulated that when the lowest of the four decks of the empty cage is on the stops at the pit bottom, the third in the loaded one is at the lower landing-level at the pit-top; and as double landing- and loading-stages are used, the second and fourth decks at the bottom and the first and third at the top are changed simultaneously, which does away with the necessity of one reversal of the engine when the top stops are used, the changing being done at the bottom on the lift and at the surface on the descent. The time required for each lift of 311 metres is 1 minute, which includes 28 seconds for the actual winding and 32 seconds for loading and changing tubs, but on rapid work it may be done in 55 seconds. This corresponds to an output of 250 tons per hour with an average velocity of 11·5 metres per second, which is the same as that realized in a second pit 266 metres deep with flat aloe-fibre ropes having an exactly similar winding-engine. The comparative wear of the ropes on the two systems, taking the best and worst examples, is shown in the following Table:—

	Koepe System.		Flat Rope.
	I.	II.	
Useful work in tons lifted	447,995	118,875	307,330
Depth of pit . . .	311 metres	311 metres	266 metres
Working life of rope .	13 months 12 days	3 months 27 days	15 months 20 days
Total work in metre-tons	139,326,400	36,970,100	81,749,700
Cost per ton of coal .	0·01 franc	0·037 franc	0·033 franc
Cost per ton of coal lifted 100 metres .	0·0027 franc	0·0101 franc	0·0104 franc

These results have been obtained under unfavourable conditions. With larger guide-pulleys and a higher pit-frame, so that both pulleys could be placed in the same vertical plane one above the other, the cost would not be more than 50 per cent. of that of aloe ropes at the present prices. For depths exceeding 350 metres the tail-rope should be made heavier than the cage-rope to assist the engine at starting. The advantages of the system are most apparent at medium depths, but at great depths it is not to be recommended, partly on account of the swinging and whipping action of the tail-rope in the pit, but more particularly because a tapered rope cannot be used. Thus for the same figure of safety at 1,000 metres the Koepe system would require a rope of 20·10 kilograms per metre as compared with 7·20 kilograms with a tapered rope winding on a spiral drum. The Author considers that the limit at which the Koepe system can be usefully employed is about 800 metres.

H. B.

Norrbotten Ores for Swedish Iron Manufacture. J. A. Brinell.

(Teknisk Tidskrift, Stockholm, 1907, General section, pp. 67–74.)

This subject undergoes an elaborate investigation by the Author, as chief engineer of the Swedish iron trade. By way of preface, attention is drawn to the fact that between 1871 and 1906 the make of pig-iron increased thirteenfold in the United States, against only 44 per cent. increase in England, the next lowest increase being 88 per cent. for Sweden.

Seven conclusions are summarized as follows:—(1) Owing to high freight-charges on ore, existing ironworks cannot be expected to employ to any greater extent the phosphorus ores from the province of Norrbotten in the north of Sweden: (2) New ironworks, erected on the coast, must export the greater part of their make; but they cannot thereby compete in price with foreign makers who employ north Swedish ores, unless they can buy ore cheaper than their competitors: (3) As long as the iron industry is dependent on imported fuel, it cannot be hoped that a make of iron using the whole or the greater part of the ore exported during recent years can be adopted and occupy an undisturbed position: (4) The electric methods of iron-manufacture are at present in an experimental stage; and even if they should be successful, they save only about half of the charcoal previously employed: (5) A larger make of iron, by the employment of peat, cannot be thought of, so long as the natural water in the peat has to be got rid of by air-drying: (6) Expectations are probably not too buoyant of getting supplies of charcoal along a future inland-railway, particularly as the object is to make iron on a large scale for export: (7) No new approved methods of manufacture are known, which could render it possible to refine at home large quantities of Norrbotten ore; and even if these should arise, several decades must be expected to elapse before they could come into general use.

In illustration of the importance of Sweden's export of ore in relation to the combined consumption by England and Germany, it is pointed out that in 1905 the export amounted to 3,316,127 tons, whereof by far the largest part went to those two countries. As their combined production of pig-iron during the same year amounted to 20·7 million tons, their whole consumption of ore must have been about 41·5 million tons, reckoning 2 tons of ore to 1 ton of pig. Thus the whole of the export of Swedish ore in 1905 corresponded with about one-twelfth of the joint consumption of ore by those two countries.

A. B.

Electrolytic Lead-Refining at Trail, British Columbia.

A. Bordeau.

(Revue Universelle des Mines, Liége and Paris, 1907, 4th series, vol. xvi, p. 165.)

At the Trail works, near Rossland, a new method of refining has been adopted, depending on the use of a solution of fluosilicate of lead in excess of fluosilicic acid as an electrolyte. This solution is stable, non-volatile, a good conductor of electricity, and dissolves lead readily. It has the same defect as other lead electrolytes of giving an arborescent crystalline deposit, producing short circuits at the anodes when used as a watery solution alone, but this defect is remedied by adding a colloid, such as gelatine or glue, to the bath, when compact deposits are obtained of the sp. gr. 11·36, corresponding to that of lead cast from fusion. The formula of the compound is $Pb\,Si\,Fl_6\;4\,H_2O$. It is partially decomposable by heat. For its preparation a 35-per-cent. solution of hydrofluoric acid is filtered through a bed of broken quartz fragments, about 2 feet thick, producing fluosilicic acid, which passes to a vat, where it is heated with carbonate of lead which dissolves rapidly. The liquor is then filtered and transferred to the refining vats. It contains 8 per cent. of lead and 11 per cent. of fluosilicic acid, as now used. As originally used it contained 6 per cent. of lead and 15 per cent. of fluosilicic acid, but this was attended by a certain polarizing effect and neutralizing of the solution at the anodes which made it necessary to scrape the anodes from time to time; this has been rendered unnecessary, however, by altering the proportion of the constituents as stated above. The refining vats, made of pine wood, are 168 in number, each containing 22 anodes of ore-furnace lead, with 358 oz. of silver and 1¾ oz. of gold per ton, and 23 cathodes of refined lead 0·06 inch thick deposited on sheet iron. It is essential that these should have smooth and bright surfaces to prevent loss of precious metals by the irregular adhesion of patches of slimes. Each vat is capable of producing 750 lbs. of refined lead in 24 hours, using 4,000 amperes, but to avoid the losses consequent on a voltage which is higher than was anticipated the rate of working is kept to 3,000 amperes and 0·44 volt per vat. The 22 anodes in each vat weigh 3 tons and dissolve in 8 or 10 days, using two cathodes for each anode. The motive power required is about 8 HP. per ton of lead, 5 amperes giving 1 lb. of lead per vat in 24 hours. 1 ton of lead takes 10,000 ampere-days or at 0·35 volt per vat 3,500 watt-days, or 4·7 HP. Adding 8 per cent. for loss in the generator and 10 per cent. for loss in the electrolyzing-vat gives 5·6 HP., or 7 HP. to 8 HP. taking into account the lighting. The lead obtained is extremely pure, bismuth and antimony being entirely eliminated, as shown by the following analysis :—

	Ore-Furnace Lead.	Refined Lead.
Copper	0·750	0·0027
Bismuth	1·220	0·0037
Arsenic	0·936	0·0026
Antimony	0·638	nil
Iron	..	0·0022
Zinc	..	0·0018
Silver	358·9 oz.	..
Gold	1·71 „	..

The amount of silver retained in the cathodes is given as 0·04 oz. (19·2 grains) per ton.

H. B.

Electric Steel-Furnaces. J. SACONNEY.

(Bulletin de la Société de l'Industrie Minérale de St. Étienne, 1907, 4th series, vol. vi, p. 141.)

This Paper records the results of an investigation made on behalf of an Italian manufacturing establishment intending to establish a steel works on a water-power in an Italian mountain district. The works visited were those of the Stassano Thermo-Electric Furnace Company at Turin, the Richard Lindenberg Electro-Steel Works at Remscheid, and the Girod Electro-Metallurgical Works at Ugine in Savoy. At each place a number of charges were worked through, and the results are given in detail, with the composition of the materials charged and the yield of finished steel. At Turin there were five charges of 11 to 12 cwt., made with pig-iron and malleable scrap of different qualities, giving steels varying in carbon between 1·2 and 1·01, 0·405, 0·280 and 0·060 per cent., but the desired carbon does not seem to have been attained within very wide limits, and the removal of phosphorus and sulphur was very imperfectly effected. The time of working a charge varied between 5½ and 7¼ hours. The waste on the metals charged varied between 5·1 and 12·7 per cent., except when a large proportion of forge scale was added to the charge, when it was reduced to 1·2 per cent. The average consumption of energy was 800 kilowatt-hours, equivalent to 1,300 kilowatt-hours per ton of steel.

At Remscheid the process is a combined one. In the first operation a Siemens-Martin charge of pig- and scrap-iron of any quality is worked in a Wellman furnace with a dolomite lining down to a good basic steel, but strongly oxidysed. This is then transferred to a Héroult rocking-furnace of about 2 tons capacity, heated by the arc from two electrodes about 14 inches square penetrating the roof. Lime and fluor-spar are added to form the slag, which is much more basic than any which can be melted in flame-heated furnaces, with the result that the ferrous oxide is reduced and the phosphorus is almost entirely removed. The slag is poured after heating about ¾ hour, and the metal is brought up to a standard of 0·600 carbon by adding petroleum-coke. For tool-steel, which

is the principal product of the works, further additions of carbon are made with so-called carburite, a mixture of very pure carbon, iron turnings and pitch, the metal being added to increase the weight and prevent the carbon from burning away at the surface of the bath.

In the record of the two charges reported the metal from the Wellman furnace contained carbon 0·02 and phosphorus 0·031 per cent., the latter being reduced to 0·006 per cent. in the electric refinery. The loss was 3 to 6 per cent. on the weight charged from the Wellman furnace. The refinery takes 2½ to 2¾ hours, and the whole operation, including that in the Siemens melting-furnace, about 6 hours. For the refining alone the expenditure of energy is about 600 kilowatt-hours per ton of steel, but if the operation started from cold materials, and included first melting, it would be 1,300 to 1,400 kilowatt-hours. A pair of electrodes, costing £5 10*s.* to £6, lasts 80 hours, corresponding to a cost of about 2*s.* 8*d.* per ton of steel.

The Girod furnace is cylindrical in form and mounted on a horizontal axis, with two apertures at opposite ends of the diameter, at right angles to the trunnions, one serving for charging and removing the slag and the other for procuring the finished charge. The lower part forming the bed is lined with magnesia and the roof with silica bricks. The current is introduced by a single electrode, about 12 inches square, through a closely-fitting aperture in the roof, forming one pole, the opposite pole being formed by a series of eight water-cooled steel castings arranged radially in the furnace-lining. In this way there is no chance of short-circuiting, as is the case when two electrodes of different polarities are used side by side, and the whole of the current must pass through the bath. The materials, either pig and scrap or scrap alone, weighing about 30 cwt., are charged in three portions, at intervals of about an hour, with lime and iron ore as required. According to the quality of the material, the operation lasts 4 hours with the best to 4½ or 5½ hours with lower quality stock. The results of five charges are given in the report, the time required being 3¼ to 5 hours, and the loss of weight 3·5 to 6·8 per cent. The consumption of energy averaged about 800 kilowatt-hours per ton, and the cost of maintenance, including wear of the electrode, about 4*s.* per ton. The furnace takes in normal work 5,000 amperes at 52 volts, and makes five casts of 26 cwt. per day, or 6½ tons, with an expenditure of 48,000 kilowatt-hours, giving a cost of about 3*s.* 9*d.* per ton at Ugine, an extraordinarily low figure, owing to the advantage of water-power. In the Saint Etienne district, with steam-driven generators, the Author estimates the cost at about £2 per ton, or with blast-furnace gas 12*s.* The general result of the Author's investigations is to prefer the Girod to the Héroult furnace, which could be built for £800 as against £1,200, for a yield in either case of 10 tons of steel for 24 hours.

H. B.

Electrolytic Corrosion of Iron and Steel in Concrete.

A. A. Knudson.

(Proceedings of the American Institute of Electrical Engineers, New York. February 1907, pp. 133–48.)

The question arises whether concrete will afford to iron and steel the same protection from stray currents of electricity as from ordinary corrosion or rust. The Author states that several instances have come under his notice in which electrolytic action has corroded metals incased in Portland cement, and laboratory experiments were instituted to throw some light on the subject. In March, 1903, some preliminary tests were made, and considerably later concrete blocks were prepared in which iron tubes were inserted. These blocks were placed in pails, some containing fresh water and others sea-water, and a current of 0·1 ampere was caused to flow continuously from the iron pipe to the water; a similar block was placed in sea-water, but no current was sent through it. These tests were made in February and March, 1906, and lasted 30 days. The block through which no current had passed was broken with the greatest difficulty, but the others had already become cracked and were easily broken; moreover, strong evidence of electrolysis was to be seen; there was a deposit of rust extending from the pipe towards the outside of the block; and, along certain lines, the cement was found to be softened, so that it could be cut readily with a knife. A further set of similar experiments were made in which the electrical resistance of the block was measured, and it was found that in 48 hours the electrical insulation of the concrete had practically broken down. Photo-reproductions of the concrete blocks, and of the iron tubes after breaking open are given, and show very clearly the corrosion and the penetration of the iron oxide into the concrete. The Author gives a practical illustration of electrolysis in a bridge over a canal at South Brooklyn, in which some rather serious cracks had developed, and it was shown that the steel structure of the bridge was positive to the trolley-rails on the bridge by an amount varying between 0·5 and 1·5 volt. In a similar bridge over the same canal the steel structure was found to be negative, and no cracks had made their appearance. From these laboratory experiments the Author concludes that although concrete preserves steel structures whether in salt or in fresh water, a very small current of electricity will produce corrosion of the metal and disintegration of the concrete. Structures in sea-water are in greater danger from electrolytic action than those in fresh water. He is unable to suggest any remedy, and states that all kinds of paint or varnishes will be of little use.

H. R. S.

Corrosion of Steel Boiler-Tubes used with Turbine-Engines.

Commander J. EDWARD PALMER, U.S.N. (ret.).

(Journal of the American Society of Naval Engineers, Washington, 1907, pp. 54–6.)

The Author describes the result of an investigation to determine the cause of serious pitting and some failures of steel tubes in water-tube boilers similar in all respects to others which lasted well. No pitting was found in boilers fitted in ships carrying reciprocating engines, the faulty tubes forming part of boilers supplying steam to turbines. A brown deposit in the pits formed nodules which invariably showed copper when analysed, while the deposit in sound tubes contained no copper. It was concluded that the pits were due to galvanic action between the copper and the steel.

The source of the copper proved to be the bronze blades of the turbine, which were eroded by the impingement of the steam. The deposit between the turbine-blades contained 1 to 2½ per cent. of copper, while that taken from one of the mud drums contained 3·6 per cent. of copper. There was evidence of the presence of organic matter in the boiler-water, the decomposition of which may have produced acids which attacked the bronze turbine-blades.

C. H. W.

Reversator Motor. S. SÖRENSEN RINGI.

(Teknisk Tidskrift, Stockholm, 1907, Shipbuilding section, pp. 37–8.)

With the employment of internal-combustion motors for the propulsion of vessels arose the desire to render them reversible. The problem of going astern has therefore attracted inventors, who have had to fall back on toothed gearing, friction-wheels, belts and ropes, or propellers with swivelling-blades. All these contrivances, however, present obviously great inconveniences. In 1902 a motor was brought out for driving astern on F. G. Ericsson's plan. The reversal of the direction of motion is effected through counter-firing during the compression-stroke, and the regulation of the exhaust-valve for one direction or the other is done through a cam on the crank-shaft; in the face of the cam is a groove, in which travels a slide-block, carried by an arm lifting the exhaust-valve. The groove in the cam-face is symmetrical; but whereas the slide-block travels along one route for forward running, it follows a different route for working backwards. This motor worked well in all respects; but the plan was applicable only to single-cylinder motors.

In 1905 the Reversator Motor Company was established with the special object of bringing out reversible motors of one or more cylinders; and 2 years' work has resulted in a highly gratifying

advance in the Swedish motor-industry. No less than ten different kinds of reversator motors of one to six cylinders of 3 to 90 effective horse-power, for working with benzine, oil-gas or spirit, have been brought out; and there is nothing to hinder their extension to still greater power. Photographs are given of a two-cylinder motor of 7, and a four-cylinder of 40 B.HP. These new motors differ essentially from the previous in the invention of two improved and simplified cams, for controlling both the exhaust- and the suction-valve. The two cams, grooved symmetrically, are carried on a separate shaft, which makes only half as many revolutions as the other cam on the motor crank-shaft. Each 90° of revolution corresponds with one stroke of the piston or one charge of the cylinder. Diagrams are given of the grooving of the two cams, which is symmetrical, but not identical. The explosive mixture is ignited by an electric spark, generated either by a battery or by a combined battery and magneto-induction apparatus. The moment of ignition is adjusted by turning the contact apparatus on its axle. The speed is controlled by throttling the gas-admission. Reversing produces practically no shock, even in a light-built racing-yacht. The Reversator Motor Company have acquired a wharf on Ramsö for the manufacture of special motor-boats. Power is furnished by a Diesel-motor dynamo of 30 HP. driven by crude oil. A photograph is given of a 12-metre (39½-foot) boat, built of mahogany, provided with four cylinders of 40 B.HP. and running at 15 knots.

A. B.

Sulzer-Diesel Reversible Marine-Engine. Prof. T. Ostertag.

(Schweizerische Bauzeitung, Zürich, vol. li, p. 167. 2 Figs.)

The Author describes in this article a special type of Diesel oil-engine as improved by Sulzer Bros., and built by them at their works in Winterthur. It is specially designed for marine purposes, and it is claimed that this is the first oil-engine which has been made so as to be reversed just as easily as the marine type of steam-engine. The propeller can, therefore, be fixed directly to the engine-shaft, and the whole arrangement is illustrated in cuts prepared from photographs. The economy in weight of fuel to be carried is very great with this type of engine as compared with the steam-engine; whereas the latter needs 2·2 to 3·3 lbs. of coal per B.HP.-hour, the former requires only 0·44 to 0·55 lb. of crude petroleum, and this being fluid can be carried in the ballast-tank. The particular engine illustrated is of 100 HP. with four cylinders, and the Author describes the arrangement in some detail. He also points out that by the use of such a motor the steam-boilers, feed-pumps, condensers, and similar accessories are all unnecessary, but that the oil-engine is somewhat heavier than a steam-engine of the same power. Another great advantage is that the fuel can be

pumped into the vessel, and passes from the storage-tank in closed pipes to the engine, so that there is no possibility of waste occurring.

E. R. D.

Gas-Engine for Heavy Marine Service. L. Nixon.

(Engineering Magazine, New York and London, May 1907, pp. 161–4.)

In view of the belief held by some prominent engineers that the steam-turbine is only an intermediate step in power-economy between reciprocating and internal-combustion engines, this communication points out that the last stage of the possibilities of the steam-engine is reached in super-heating the steam, and deals with the difficulty of holding in bounds steam at 250 lbs. pressure. As to the turbine, only time will show how the requirement of a very high vacuum for high efficiency will work out in practice, and in both the pitiable conditions of the men in the engine-room are enlarged on. Horse-powers of 1,000 in one-cylinder gas-engines are now common, and the superiority in economical conditions to the best types of steam-engines has been demonstrated. The Author, who has been in the construction branch of the U.S. Navy and President of the U.S. Shipbuilding Company, is convinced that gasoline and alcohol are the ideal liquid fuels for gas-engines for all descriptions of war-vessels under 20,000 HP., where great speed and endurance are required, and weight and space must be reduced to the minimum. The influences which force the recognition of the gas-engine in place of the steam-engine on the water are classed as (1) Simplicity, (2) Less strain on the engine-frame, (3) Less weight and space for the same power, and (4) Greater economy. Examples of the adoption of the principle are then given and the producer problem is adverted to, hard-coal gas-producers being now in general use with good results, and soft-coal producers needing development. The next important step will be a simple and easily manipulated crude-oil gas-producer. The article concludes with the statement that 100,000 HP. can be installed in the space and on the weight of 45,000 HP. of steam, as put on a modern liner, the consumption of crude-oil in that case being about 750 tons per day.

The largest marine-engine yet designed on approved data is stated to be a six-cylinder double-acting engine of 33-inch diameter by 33-inch stroke, developing 5,000 HP. at revolutions less than 200; but far larger units are in use on shore, and their application on water is an easier problem than on land.

C. O. B.

Rainfall and Run-off in the North-Eastern United States.

JOHN C. HOYT, Assoc. M. Am. Soc. C.E.

(Proceedings, American Society of Civil Engineers, vol. xxxiii, p. 452.)

This investigation was undertaken to ascertain the relation between rainfall, as measured by the United States Weather Bureau rain-gauges, and the discharge of the water in streams and rivers in various catchment-areas, figures for the latter being taken from the records of the United States Geological Survey. For comparison, both rainfall and discharge are expressed as depth in inches over the drainage-basins considered. In the higher latitudes irregularities are introduced into the comparison by the difficulty of estimating the water-value of the snow-fall. The areas considered range between the Connecticut valley and the James River valley, and the records extend over varying periods of 5 to 21 years. The results are given in lengthy Tables, and a general survey shows that the discharge decreases towards the south although the rainfall increases. It is about 60 per cent. of the precipitation in the northern areas, 55 per cent. in the intermediate, and 40 per cent. in the southern. This decrease in discharge is attributed to the increase in evaporation and the loss by vegetation. The actual loss in rainfall increases towards the south, being 15·10 inches in the Connecticut and 24·99 inches in the Roanoke drainage-area. The mean loss for frozen areas is 17·7 inches, and for southern areas 24·13 inches.

R. S. B.

Deep Bore-Holes.

(Engineering News, New York, 23 May, 1907, p. 567.)

In connection with the Catskill water-supply for New York, diamond-drill borings as deep as 500 feet were necessary. As these often deflect much from their true course, an instrument for determining their true direction, devised by Mr. J. J. Horan of the engineering staff, was used. It consists of a brass casing in which is placed a closed glass cylinder containing gelatine or paraffin-wax, and having a compass mounted on gimbals suspended in it. A coil of resistance-wire surrounds the glass jar. The whole apparatus is lowered to the bottom of the bore-hole by the drill-rods, and a current is passed through the wire. The heat melts the paraffin, and the compass-box assumes a horizontal position while the needle points north. As the wax cools and solidifies the compass and needle become clamped thereby in position, and the whole instrument is raised to the surface. Another instrument, both being minutely described and illustrated, was invented by Mr. Horan for

measuring the indications of the instrument removed from the bore-hole.

In the same article a device for testing the porosity of the rock penetrated by the bore-holes is explained. It consists of a spring of soft-rubber disks strung on a tube and held between metal washers. Above there is a larger tube. The two tubes, with the washers at their lower end, are lowered down the drill-hole, and at any desired point the coupling connecting the inner and outer tubes above-ground is screwed up until the rubber disks are compressed and expanded to make a tight joint with the sides of the bore-hole. Water is then forced into the space in the bore-hole around the outer tube, and the extent of the leakage from the bore-holes, if any, is determined. The dimensions of this apparatus are given in the cuts.

C. O. B.

Increasing the Height of the Lennep Dam. ALBERT SCHMIDT.

(Zeitschrift für Bauwesen, Berlin, vol. lvii, pp. 227–32.)

An account is given of the circumstances under which a reservoir in the valley of the Panzerbach was constructed by the Author in 1893 for the supply of the town of Lennep with water. This reservoir had a capacity of about 26,400,000 gallons. The dam had a total height of 37·72 feet and a length at the crest of 416·57 feet. Owing to the inclusion of a larger population and the important railway-junction at Lennep in 1894, the supply from the reservoir gradually proved to be inadequate, and in the very dry season of 1901 it was no longer possible to obtain a sufficient volume of cool and unobjectionable water. It was proposed, therefore, to procure a further supply, and for this purpose the Author prepared a scheme in accordance with which the height of the dam was to be increased by 10·66 feet, and the structure at the same time was to be stiffened with buttress-piers. By this means the water-level was raised 9·84 feet, and the total capacity of the reservoir was brought up to about 60,000,000 gallons. This plan was approved by the Minister of Public Works, and has been executed under the Author. The wall was simply raised on the old substructure, retaining the existing curvature to the increased height. At distances of 41 feet from centre to centre, twelve piers, each 9·8 feet in width, have been erected on the exterior side of the dam, which at the deepest part of the wall are 26·24 feet, at the old crest 10·66 feet, and at the summit level 7·38 feet in advance of the face of the original dam. At about half their height these piers are united by means of concrete arches, and at the ends of the dam these arches are firmly connected with the rock by cementing the spaces between the piers and the rockwork. The piers are likewise tied at their summits with arches in masonry, and certain other measures adopted to consolidate the new work and the old are explained

by reference to detailed illustrations. In order to study the movements in the dam caused by fluctuations in the water-pressure and due to alterations in temperature, there are at either extremity well-founded stations for inspection, and two points have been arranged for observation in the structure of the dam which can be shifted by means of micrometer screws, and render it possible to read off any changes in the position of the mass. The bending-moment of the dam when the reservoir was first filled amounted under water-pressure to 3 millimetres, and later measurements of 4 millimetres, caused by changes of temperature, have been recorded. It is stated that it would appear from calculation that the employment of piers in lieu of a wall of full thickness has led to a saving of 16 per cent. in the cost.

G. R. R.

Ellsworth, Maine, Reinforced-Concrete Dam.

(Engineering News, New York, 23 May, 1907, p. 557.)

This dam, it is stated, has the highest head of any of its type, viz., the hollow system patented by the Ambursen Hydraulic Construction Company of Boston, U.S.A. The dam, 64 feet 6 inches in height, the spillway being 300 feet long, is triangular in section, the downstream slope (7 to 12) being eased by reversed curves at the overfall and toe. The faces, 3 feet 1 inch thick at foot and 1 foot 2 inches at top upstream, are connected by transverse walls or counter-forts 2 feet thick at bottom gradually stepped up to 1 foot at top and 15 feet centre to centre, which are, in turn, connected by beams 12 inches by 18 inches. All these are of concrete 1 : 2 : 4 in face, and 1 : 3 : 6 elsewhere, reinforced by high-elastic-limit Johnson bars, the position of which appears on the sections, these also showing the lines of pressure. The resultant of the pressures during the flood of 6 feet 6 inches allowed for on the base, which is rock, cuts the foundation 6 feet 6 inches upstream from the centre line of the base, instead of the downstream edge of the middle third, as is customary in solid masonry dams. The maximum compressive-stress in the concrete of face is 500 lbs. and in the steel 12,500 lbs. per square inch.

One of the principal claims of superiority made for this special design is the advantageous distribution of the stresses, and owing to the long and low back-slope the water behind the dam acts as a helping weight as well as an overturning force. The power-house with its equipment, which is supplied from the water backed up, is briefly described, the whole work being expected to be finished by January, 1908.

C. O. B.

Collapse of a Madrid Vaulting Reservoir.[1] Dr. VON EMPERGER.

(Revista de Obras Publicas, Madrid, vol. lv, p. 193. 7 Figs.)

This article describes the method of construction in reinforced concrete of the vaulting of a very large reservoir at Madrid by Mr. Ribera, and the collapse of the structure when only partially finished. The constructor had already built twenty-five other smaller reservoirs, and had made special tests of the strength of vaulting for a reservoir of similar character at Gijon before designing the reservoir at Madrid.

The total area to be covered in was about 95,680 square yards, divided into four compartments; the central division-wall was of brick, and the other two of reinforced concrete. At the time of the collapse the vaulting over one-fourth of the area and about half the vaulting over two of the other quarters had been completed, while work on the fourth quarter had not been commenced.

Tests were then made of the vaulting of the completed quarter. The load for which the vaulting was designed was 143·5 lbs. per square foot, and the test-load of 50 per cent. more was produced by a layer of earth.

The deflection during this test was only about 3 millimetres at the crown of each vault, which was considered very satisfactory, and the load was reduced to a layer of soil 10 inches thick, which was to remain as the permanent covering. When about half this work had been done, a large part of the structure collapsed, killing twenty-nine and wounding forty-six workmen.

It appears probable that, if the whole construction could have been completed while there were no great variations of temperature in the atmosphere, and if the vaulting could have been covered with earth to the specified depth and the reservoir filled with water, there would have been no accident. Such conditions were, of course, impossible of fulfilment, and there is no doubt that the collapse was caused by the great variation in temperature between the nights and days in the summer in Madrid. These changes caused stresses in the vaulting, which finally produced the collapse. The Author remarks on the absence of strutting between the columns supporting the vaulting, except that provided by the three cross-walls.

E. R. D.

[1] A copy of the Official Reports on the collapse is in the Library of The Inst. C.E. —SEC. INST. C.E.

Protection of Water-Mains from Rust. H. WEHNER.

(Gesundheits-Ingenieur, Munich, 20 April, 1907, p. 245 *et seq.*)

It is pointed out that the injury caused to metal pipes by the presence of rust is well known, but that it is doubtful whether sufficient attention is paid to the origin of this evil, and though it is often assumed that the growth of rust is due to one general cause, this is by no means the case. Of all metals used for industrial purposes, iron is most exposed to the action of oxidation, and three separate varieties in the decay or destruction of iron by rust can readily be distinguished. The first takes place in the form of coarse blotches or blisters of rust on the interior of pipes, which as a rule run full of water, and on the exterior of pipes which are laid in a damp or salt soil. The second kind of decay arises as a very fine, more or less brightly-tinted, but usually yellowish mud, found in the interior of pipes. The third form of destruction of iron is much more rare, though it is now more prevalent than formerly. It gives no outward token of rust; in fact to the eye the iron may appear wholly unchanged, and it can only be discovered by minute inspection of the structure of the metal. It is quite possible for this species of decay to take place leaving the protective coating of lacquer or paint wholly undamaged. But when a hard and sharp substance is thrust into the metal it penetrates it readily. This is known as the "graphitic" destruction of iron. This term is entirely erroneous and causes misconception; it would be better, therefore, to substitute for it the term "sponge-like decay." In order to deal with these attacks it is necessary to understand how they come about, and a description is given of the chemical nature of the reaction which causes the presence of rust. In the case of the sponge-like decay, though this may be effected by the action of weak acids, Freund has recently shown that it is possible with a very feeble electric current (a few tenths of an ampere to 100 square centimetres of iron) to obtain exactly this decomposition. This spongey state of iron was examined by Calvert so far back as 1861, and it is pointed out by the Author that iron consists largely of pearlite and cementite, and that if, as appears possible, the bulk of the silicon in grey cast iron be combined with the cementite, the pearlite contains the combined carbon. The iron alloyed with the silicon is capable of resisting electrolytic action, while the pearlite is destroyed. Some micro-photographs of thin sections of iron to illustrate these views are given, and the observations of a series of writers on the subject are recorded. Various methods of combating the electrical and other forms of the corrosion of iron are explained, and it is suggested that it might be possible to select qualities of metal better capable of resisting destructive influences than those now used, since white pig is more free from attack than grey pig, and the iron used 100 years ago, smelted with charcoal, is better able to resist rust than the modern cast iron.

G. R. R.

Sydney Water-Supply and Sewerage.

Eighteenth Annual Report of the Metropolitan Board of Water-Supply and Sewerage, Sydney, N.S.W., 1905–6, issued May 1907.)

The Board controls the water-supply and sewerage works of the metropolitan area of Sydney. It is composed of a President, appointed by the Government, two members who are aldermen of the City Municipal Council, two members elected by the Suburban Municipalities, and two official members representing the Government.

The capital cost of works, water and sewerage, in 1888 and 1906 is given as under:—

	1888	1906
	£	£
Waterworks	3,004,557	4,847,978
Sewerage-works	1,281,045	4,330,397

The Revenue was:—

	£	£
Waterworks	125,486 (1888)	270,263
Sewerage-works	81,800 (1890)	220,629

The Interest after paying expenses:—

Waterworks	Per cent.	3·81 (1888)	4·40
Sewerage-works	,,	5·06 (1890)	4·32

The mileage of water-mains, including trunk- and pumping-mains, at the end of 1905–6 was 1,336⅓ miles. During the year 60⅓ miles of mains were laid. The mileage of sewers was 656¾ miles, together with 44¾ miles of storm-water channels. The population of the area served by the Board is given as 581,010. The average daily consumption per head was 38·54 gallons. Water is supplied to 144,116 properties. The sewers are connected with 88,881 houses, representing a population of 444,405.

It is stated that 66¾ miles of pipes were cleaned during the year. This includes 4·85 miles of 72-inch steel mains. This pipe had been in constant use for 19 years, and the exigencies of supply prevented attention being given to its internal condition. About 200 men were engaged, and the time occupied in cleaning and re-coating with a cement was 8 weeks. The cost was £2,800. About 1,000 cubic yards of debris were removed. Ventilation was secured by hand-worked "champion" blowers attached to air-valves in the main. A good draught of fresh air was ensured, and the men worked in comfort. The plates were found to be in excellent condition.

There are now fixed 18,102 water-meters of the inferential type. Reference is made to the efficiency of the pumping-plant. Of the total volume consumed per annum, 5,339,000,000 gallons were raised by pumping. At the chief pumping-station the cost of lifting 1,000 gallons 100 feet high was, for 1906, 0·22*d.*, at Ryde 0·30*d.* Although the rainfall was much below the average, and less than

that which fell during the drought period of 1902–3, the volume of water available was greater than at that time, by reason of the incidence of the falls.

Improved telephonic communication, with metallic circuit, has been instituted throughout the entire system. Electric current is now taken from the City Council Station and used for lighting and motive-power at the Depôt and the Lighting Board's various establishments. An electrically-driven pumping-plant has just been installed at the Crown Street Station. It consists of a 700-HP. induction-motor placed between, and directly coupled to, two high-lift centrifugal pumps. Electricity in bulk is supplied by the City Council at 1*d.* per Board-of-Trade unit.

Improvements have also been made in the northern-suburbs supply by the installation of Parsons turbo-centrifugal pumps at Ryde. One set raises 1,500,000 gallons per day 700 feet through a 15-inch locking-bar steel pipe, and the other set 3,333,333 gallons per day 240 feet through a 32-inch main. A new battery (5) of Sterling boilers has been erected.

Sewerage.

It is stated that upwards of 1,581 tons of silt were removed from the outfall-sewers and low-level system of the City, while 1,550 tons were removed from suburban sewers. The volume of sewage lifted by electrically-driven pumps at all stations amounted to 1,156,478,000 gallons, the electrical energy absorbed being 625,993 B.T.U.

The plunger pumps in the low-level zones of the Metropolitan system are referred to as causing much anxiety and expense, and it is stated to be the Board's intention to substitute centrifugal pumps at all stations. The open septic tank at North Sydney has been roofed in, and the complaints of residents regarding unpleasant smells have entirely ceased. The sand filter-beds are working well, and the effluent is chemically excellent. Reference is made to the generally satisfactory condition of the works throughout.

In the financial section of the Report it is stated that the revenue from the Water Branch had increased by £18,760; while the working-expenses, including maintenance and management, were reduced by £1,528. The gross revenue was £270,263, and the working-expenses £64,487, or 23·86 per cent. of the gross revenue, leaving a net revenue of £205,776, or 4·40 per cent. on capital cost. The sewerage-branch revenue was increased by £6,692. The working-expenses were £1,055 more than those of the previous year. The gross revenue was £220,629, and the working-expenses £55,368, or 25·09 per cent. of the gross revenue—leaving a net revenue of £165,261, or 4·32 per cent. on capital cost.

C. W. S.

Adsorption[1] *of Colloidal Sewage-Constituents.*

Professor Dr. W. Biltz and Dr. O. Kröhnke.

(Gesundheits-Ingenieur, Munich, 25 May, 1907, pp. 350–4.)

It is pointed out that the Authors demonstrated some years ago that an important part of the components of town-sewage capable of being oxidized is in a state of colloidal solution. These constituents of sewage liable to putrefactive changes can, when isolated by means of dialysis, readily be shown in various ways to be colloids, and this removed all doubt on this question. This fact seemed to point to an explanation of the method by which in the technical process of sewage-purification the reagents employed come into operation. Attention is directed to recent researches, mainly discussed by English and American authors, and to results obtained by Winkelblech and Koch, as also to the value of the process devised by them for clearing turbid water. When a watery colloidal solution is agitated with an organic solvent, not capable of mixing with water, the drops of the finely-divided organic fluid draw out the small colloidal particles in the solution and form a layer of froth, sharply separated from the watery solution. In an experiment here described the layer is said to have the appearance of an emulsion of oil. By means of tables and graphic diagrams illustrations are given of the reactions observed by the Authors. Reference is also made to the action of micro-organisms in the purification of sewage-water and to the connection between this action and the colloidal state. After giving the results of certain adsorption experiments with typhoid-fever bacilli and agglutinous albuminoid matter, the Authors consider the biological process of sewage-purification to be one in which primarily the colloidal putrefiable substances are united by means of adsorption to other colloidal matters, for which purpose, owing to their character and power of regeneration, micro-organisms are specially well adapted.

G. R. R.

Sewer-Tunnelling in Hamburg. Curt Merkel.

(Deutsche Bauzeitung, Berlin, 1907, 4, 11, 15, 18, 22, 25 May, 1 June, pp. 254–6, 263–8, 270–5, 286–7, 295–9, 309–11.)

The Author describes in a long article the recent sewer-tunnelling work at Hamburg carried out in connection with the construction of two new main intercepting-sewers. These two new sewers have a total length of 9,700 yards, of which about 5,300 yards were constructed in tunnel, partly under air-pressure with a shield, partly with a shield alone, partly with air-pressure without a shield, and lastly, for a short length only by ordinary methods. The works

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[1] Adsorption is a coined word to denote colloidal adhesion.—G. R. R.

involved a total expenditure of £435,000; the 9-foot 10-inch circular cross-section constructed with a shield and without air-pressure costing £50 per yard, and the 7-foot 10-inch circular-section by ordinary methods £19 10s. per yard, with air-pressure without shield £30 10s. per yard, and pneumatically with a shield £41 per yard. The sinking of the shafts prior to tunnelling and the tunnel-work itself were executed under extreme difficulties owing to the unstable subsoil strata and the subsoil water. The shafts had to be built up to the top level of the quicksand in heavy masonry, as the timbering could not withstand the shifting pressures. It was decided to execute the sewers in brickwork instead of an iron lining, owing to the greater expense of the latter. The necessary power was supplied from a central station, and it was found that the pumps required 34–74 HP., the hydraulic power for the shield 10–25 HP., the electric installation 10 HP., and 1 HP. for every additional 100 yards of tunnel constructed, whilst the air-pumps absorbed 36 to 169 HP. in accordance with the pressure and the amount of air necessary, which was 10,000–14,000 cubic feet per hour. The design of three tunnel-shields used was left to the contractors. They were of circular cross-section with an external diameter of 10½ feet and 19 feet long. They were made of a double thickness of mild steel, about ½ inch thick, lap-riveted, and the front working-chamber had a cast-iron lining 1½ inch thick. The tail of the shield formed the temporary lining for the brick-work. The working-chambers were first designed with 6 compartments, which in working proved impracticable, and division-plates were cut away. The hydraulic presses were 8 in number, being 5½ feet long, 4¾ inches internal diameter and 2 inches thick, and were of cast steel. They were calculated for a maximum pressure of 500 atmospheres, equal to 48·4 tons per press, and capable of exerting together a total pressure of 387 tons. The actual pressures used varied between 40 and 400 tons, the latter being required at changes of direction. Great difficulties were experienced with the air-pressure, for, if the pressure was sufficient to work in the upper chamber, the water rose in the lower chamber, and when the extra pressure was applied to retain the lower chamber dry, the air escaped immediately upwards through the porous soil. The methods of internal blanketing to overcome these losses are fully described. As the sewers were to be constructed in brickwork, special precautions had to be taken in regard to the cement. A medium quick-setting cement was first used with a set of 2–4 hours, but after repeated trials a cement with 4–8 hours' set was finally used, as it was proved that the pressure due to driving forward the shields had no injurious effect on the setting of the cement and the stability of the brickwork, as the cement always had a period of 3–5 hours' rest before the pressure was applied. The space between the brickwork and the excavation left by the advance of the shield was grouted in by a Greathead grouter under pressure.

The article is illustrated by a great number of photographs and detailed drawings of the works. F. R. D.

Ballston Spa, New York, Sewage-Disposal Works.

G. L. ROBINSON, ASSOC. M. AM. SOC. C.E.

(Proceedings, American Society of Civil Engineers, vol. xxxiii, p. 511.)

Owing to an order prohibiting the further use of the Kayaderosseras river for the purposes of sewage-disposal, the village of Ballston Spa, which has a population of about 6,000, undertook the construction of a sewage system. The works were designed to handle daily 500,000 gallons (U.S.) of domestic sewage, 400,000 gallons of tannery wastes, and 100,000 gallons of possible infiltration. The minimum daily flow of the river being 30,000,000 gallons, the works were planned to produce an effluent which would be free from deleterious matter and would mix quickly with the water in the river.

The plant consists of a receiving-tank which is set on flat gravel soil 150 feet from the river. It is 70 feet in diameter, is constructed of armoured concrete, and when full will contain 259,000 gallons, or 25 per cent. of the daily flow. It is divided into two compartments by a concrete wall 36 inches thick at the bottom and 20 inches at the top. By means of the gates the sewage may be turned into either compartment to facilitate cleaning, and the roof of the tank is designed to support a dead load of 1 foot of earth-covering and 5 feet of water. From the tank the sewage passes through two 16-inch by 16-inch openings into the suction-chamber, from which it is delivered through a 12-inch main, 2,700 feet long to the septic tanks and contact-beds. There are two single-acting 12-inch by 14-inch plunger-pumps electrically driven, each with a capacity of 800 gallons per minute. By means of these pumps a constant flow of sewage to the septic tanks is maintained. There are three septic tanks of reinforced-concrete walls located on a hilltop, each being 111 feet long, 35 feet wide and 8 feet deep at the inlet, and each holding approximately 218,000 gallons. In each tank, 3 feet from the outlet, there is a timber baffle-wall which may be readily raised or lowered by gearing. There are also three weirs 6 feet long and a coke-breeze filter 2 feet deep and 2 feet wide, extending the full width of the tank. After passing through the filter the effluent flows out through a 12-inch pipe to the four contact-beds, which are each 120 feet long, 90 feet wide and 6 feet deep, the walls being of concrete, 1 foot thick at the top and 2 feet at the bottom. The contact material is graded, being for the lower 18 inches 2-inch and 3-inch broken stone, for the next 3 feet 1½-inch stone, and for the upper layer 2-inch stone. The beds each hold 130,000 gallons of sewage, and may be worked in any combination.

R. S. B.

Briquettes from Coke-Dust. MAX ROSENKRANZ.

(Journal für Gasbeleuchtung und Wasserversorgung, Munich, 9 March, 1907, pp. 197-9.)

The quantity of coke-dust produced at the Riga Gasworks amounts to 4 to 6 per cent. of the weight of coal carbonized. This dust, which consists of very small coke up to the size of a pea, is produced mostly whilst breaking large coke, and to a certain extent during conveyance and storage of the material. The formation of dust seemed to be increased by exposing the coke to the action of frosty and wet weather. Small coke or coke-breeze varies in size between ¼-inch and 1-inch pieces and is suitable as fuel for boilers, but the dust from which this is sieved has a small market-value and only a limited use for building purposes and is quite unsuitable for boiler-fuel as it is carried into the flues unburnt. Again, this coke-dust yields only about one-ninth the price of breeze, which, considering its heat-value, is very low.

The Author has tried for some time to obtain a suitable binding-material by means of which the dust may be compressed into briquette form, and has found that a mixture of thick tar and hard pitch gives satisfactory results. A compressing-machine has been at work for about a year at Riga and is capable of producing 1,000 bricks per hour, each weighing about 14 ounces, representing about 8 cwts. of briquettes per hour. The binding-material, which constitutes about 5 per cent. by weight of the total, is mixed with coke-dust in a chamber above the dies, and is treated with superheated steam for purposes of drying. The briquettes formed burn well and do not fall to dust in the fire; the calorific power is practically the same as that of coke.

The following working-costs are cited:—

	£	s.	d.
1,430 tons of coke-dust would yield at its highest price	161	0	0
100·2 tons hard pitch	466	19	0
15·8 tons thick tar	30	12	0
Wages	134	0	0
Repair and maintenance	53	8	0
Depreciation—10 per cent. machinery, 4 per cent. buildings	34	4	0
Interest on outlay at 6 per cent.	30	5	0
	910	8	0
The net profit is	881	13	0
Amount realized by sale of briquettes	1,792	1	0

Both the working-expenses and wear-and-tear of plant are high, but the Author foresees a possibility of reducing these. Again, the quantity of pitch used can be reduced. Notwithstanding these high figures there is a distinct advantage to be gained by manufacturing briquettes from coke-dust.

The briquettes produced are quite suitable for boiler-fuel and can well be used in the producers of retort-settings as they form little clinker.

E. V. E.

Vertical Retorts. EISELE.

(Journal für Gasbeleuchtung und Wasserversorgung, Munich, 5 January, 1907, pp. 1–7.)

The Author having described in detail the principles involved in the construction of three typical vertical retort-settings, the Dessau, Settle-Padfield and Woodall-Duckham, compares their respective advantages as regards facility of working, based on his experience in gas-manufacture.

The aim of the inventor should be to construct retorts suitable for continuous working, and, together with the formation of water-gas, to produce coke already quenched and thereby cool. To a degree these conditions have been realized, and notably in the cases of Settle-Padfield and Woodall-Duckham, but working-results are not published. With these two kinds of settings the charging- and discharging-apparatus are not easy to manipulate, and in the case of the Settle-Padfield retort, the discharging having been carried out periodically, carbonization was not uniform, although the uniformity of carbonization seemed to be better than obtained with the Dessau retort.

The yield of gas and ammonia is found to be higher with the Woodall-Duckham retort, where the steam obtained by quenching the coke is generated in the retort, and the suggestion put forward that the quality of the coke is impaired by the introduction of steam into the retort is without ground, as the quantity of steam which can be generated by quenching 100 lbs. of coke can only oxidize 1 lb. of carbon.

From the experience already gained with vertical retorts it seems that the following facts are well established:—

1. Carbonization in vertical retorts is possible, and more favourable results are obtained than with horizontal and inclined retorts.
2. The durability of the retorts, their steady and easy working, and their better carbonizing results have been established without doubt, and especially in the case of the Dessau retort.
3. In order to obtain the nitrogen of the coal in the valuable form of ammonia steam must be admitted to the charged retorts, and the maximum yield of ammonia is obtained if the steam-supply is augmented as the temperature of carbonization rises.
4. A larger amount of steam increases the volume of gas produced, but the calorific power is reduced (this latter should not fall below 560 B.Th.U. per cubic foot), and under certain circumstances the quality of the coke is also reduced.
5. If only the steam employed to quench the coke be admitted into the charged retort the quality of the coke is scarcely affected.

E. V. E.

Small Regenerators for Retort-Settings. HERMANNSEN.

(Journal für Gasbeleuchtung und Wasserversorgung, Munich, 29 December, 1906, pp. 1133-6.)

The best results as regards fuel-economy seem to be obtained by a large regenerator supplying a setting of eight retorts in which the coke consumed is 11 to 14 per cent. A question of considerable interest, especially to smaller gasworks, is whether a similar efficiency can be obtained without the erection of a large and expensive regenerator. In settings where there is a large number of retorts the expense of an elaborate regenerator is very great; moreover, the retaining-walls and general structure are so large that an abnormal loss of heat is inevitable. A setting of eight retorts was worked for 24 hours, the retorts being charged, and the fuel-consumption was 11·5 per cent.; the same setting worked another 24 hours with the retorts empty, showing the fuel-consumption to be quite a third less, the efficiency of the setting being about 35 per cent.

The Author describes the Pintsch-Hermannsen regenerator, and three drawings are given to detail its construction. A number of fireclay pipes grooved transversely on the outside are so laid as to allow the grooves to coincide and form channels through which the secondary air passes, whilst the waste gases travel through the pipes in a longitudinal and opposite direction. The depth of the regenerator is about 4 feet, and allows a heating surface of 57½ square feet per retort, representing 40 to 70 per cent. more than obtained by an ordinary regenerator 10 feet deep, or, per unit of space; there is five times as much heating-surface as with the usual form of regenerator.

Some results obtained from a setting of this type for six retorts gave a fuel-consumption of 11·4 per cent. Later, short tests were undertaken in which the gas made per ton of coal carbonized was 11,196 cubic feet, and the yield of coke 70·5 per cent. by weight.

It is suggested that the form of regenerator described not only renders the erection of a deep regenerator unnecessary, but possesses itself very distinct advantages.

E. V. E.

Mechanical Action of Electric Currents in Conductors. P. BARY.

(L'Éclairage Électrique, Paris, 1907, vol. li, pp. 37-49.)

When an electric current is passing through a conductor it is subjected to electromagnetic forces which tend to reduce the section of the conductor, and if the conductor be liquid, it may even be ruptured. The Author describes a large number of experiments which show that these phenomena of electromagnetic striction are quite general and apply to all conductors traversed by a current.

In solid conductors the effect cannot be observed on account of the great cohesion of the molecules and of the low coefficient of compressibility of the metals. In liquid conductors a tendency to rupture can always be observed on account of the greater mobility of the molecules, and sometimes actual rupture is produced. This tendency is accompanied by movements in the liquid, and when the current is alternating or discontinuous, these movements show themselves by giving a wavy form to the surface of the liquid. In gases at ordinary pressure, the mobility being greater than in liquids, marked effects of striction are observed with relatively feeble currents, and the variations of section of the conductor follow closely the variations in the intensity of the current, even when these are very rapid (as in the speaking arc); when the intensities and the dimensions of the gaseous conductor are suitably chosen, a periodic rupture of the conductor may be obtained (as in the singing arc). In rarefied gases the effects are still further increased, and these explain the fact that the current traversing a vacuum tube, even under constant potential difference, is always discontinuous.

W. C. H.

Transformation of Electric Power into Light, and New Types of Glow-Lamps. (Discussion on Paper by Dr. Steinmetz.)[1]

(Proceedings of the American Institute of Electrical Engineers, New York, January, 1907, pp. 83–97.)

Mr. Herschel C. Parker, in confirmation of Dr. Steinmetz' statement that it was not the high melting-point of refractory substances that determined the efficiency of filaments, but that it was the point of disintegration or vaporization, said that he had been experimenting with a substance of which the melting-point was only about 1,400° C., and yet had given an efficiency of about 1 watt per candle, with an average life of 700 to 1,200 hours; it was almost impossible to vaporize this substance. Mr. John W. Howell was of opinion that the osmium, tantalum, tungsten, and other new lamps, constituted a revolution in the art of glow lighting, and that whereas in the case of the carbon filament an experience of 16 years had only increased the life 2·5 times, the tungsten lamp was at least 300 times as long-lived as the carbon lamp at the same efficiency. Mr. Percy H. Thomas thought that high intrinsic brilliancy was harmful because it produced a contraction of the pupil of the eye, so that less effective use was made of the illumination. Mr. C. W. Hogan referred to an investigation he had made to determine the relative radiating-surfaces of filaments of triangular section as compared with the usual circular section, and he had obtained the result that a filament of

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[1] Proceedings of the American Institution of Electrical Engineers, November, 1906, pp. 755–79.

triangular section would have an efficiency of 1·74 watt per candle-power as against 3·31 watts for the circular section.

Dr. Steinmetz, in reply, agreed as to the increased area of the triangular section, and that it would radiate more light, but also it would radiate more heat, so that on the whole there would be no advantage. He pointed out that the physiological effects of different colours of light had not yet received much consideration, but would now deserve careful study because widely different colours were now available varying between that of the flame carbon and that of the mercury arc. It would appear that the physiological effect of lights of different colour did not follow the law of inverse squares of the distance but varied faster with red and slower with green light. Hence a green light was best for illumination when a low intrinsic brilliancy was desired, and red for advertising purposes.

H. R. S.

Power-Measurement by Wattmeters on Lamp-Circuits.

H. PÉCHEUX.

(L'Éclairage Électrique, Paris, 1907, vol. li, pp. 289–98.)

The approximation of the reading on a wattmeter in a lamp-circuit to the true power consumed depends on the relation between the resistances of the wattmeter coils, the resistance of a lamp, and the number of lamps in the circuit; and a comparison of these possible errors enables the electrician to arrive at the best arrangement to adopt to keep the error as low as possible. But this error is generally referred to the power consumed by the lamps, which is in fact unknown, whereas it ought to be referred to the power indicated by the wattmeter. Following this plan, the Author discusses from first principles the determination of the constant of any wattmeter employed on a continuous-current lamp-circuit, and the magnitude of the errors which may appear, under different conditions and with different loads, in the readings of (1) torsion-wattmeters and (2) motor-meters. He shows that as the constant fixed by the maker for each motor-meter always corresponds to the maximum load, there may be large errors in the readings, involving considerable losses for the central station, when the consumer is only using a portion of his lamps. This defect, taken along with other mechanical and electrical sources of error, makes the motor-meter less reliable than the torsion-wattmeter; but the latter can only be made a registering instrument by letting the pressure-coil swing freely, and by attaching to it a light pointer-pen leaving a trace on a clockwork-driven drum.

W. C. H.

Electric Transmission of Images. Henry.

(L'Électricien, Paris, 1907, vol. xxxiii, pp. 246, 265, 281 and 296.)

These articles contain what the Author believes to be an almost complete history of the work done by different investigators on the subject of the telegraphic transmission of images. They deal both with teleautography and telephotography.

W. C. H.

Electrolytic Production of Calcium. J. Escard.

(L'Éclairage Électrique, Paris, 1907, vol. li, pp. 264–70.)

The Author describes in this article all the attempts which have been made, and the processes employed, for the production by electrolytic means of pure metallic calcium, and also of alloys of calcium with other metals. The problem is of importance from the fact that the properties of calcium make it specially suitable for those metallurgical applications which require the use of reducing substances to purify certain metallic baths at the moment of tapping. Its strong affinity for nitrogen might be widely applied in practice. Although up to the present only small quantities of the metal have been produced by the different processes, the Author thinks that soon the production of large quantities by electrolytic processes will be assured, and that calcium will then be used largely and advantageously as a substitute for aluminium in the metallurgy of iron.

W. C. H.

Alternating-Current Electrolysis. J. L. R. Hayden.

(Proceedings of the American Institute of Electrical Engineers, New York February 1907, pp. 103–31.)

Gas- and water-pipes, etc., can be protected from electrolytic corrosion in the case of direct current by connecting them to the negative terminal of the circuit; this method is obviously not feasible with alternating currents. In 1906 the Author undertook an investigation to determine whether, and to what extent, alternating currents passing between any metallic conductor and the ground would produce electrolytic corrosion. The tests made included different current-densities and different frequencies. A first series of tests were made with diluted solutions of such salts as may be expected in the ground, then different kinds of soils were investigated, after which tests were made on a typical soil by adding carbonates, sulphates, organic matter, etc., and lastly, the possibility of protection against electrolysis was investigated. In the first tests plates of lead and sheet iron were used, but in the latter only lead

plates, because the relative unimportance of iron had been proved. The method of making the tests is fully described and the results are given in a tabular form. There are altogether twenty-one Tables which require some study to appreciate the results obtained; broadly they are as follows:—There is no apparent relation between ordinary chemical corrosion, that is, corrosion taking place without any current, and electrical corrosion. Iron is in general less attacked than lead, hence with alternating currents difficulty is not likely to arise unless large currents are passing between the rails and iron pipes and the effect on lead cables is the more serious problem. It appears that it is possible to protect lead cables against chemical corrosion by surrounding them with alkaline sulphates, but no appreciable protection is thus obtained against the electrolytic action of alternating currents. In general the lower the frequency the greater the electrolytic action; with carbonates, however, the effect is reversed, and with alkaline nitrates, chlorides and mixtures of salts, frequency has no apparent effect. Electrolytic corrosion is very greatly increased by increase of temperature. Definite quantitative general laws cannot be formulated in the case of alternating-current electrolysis as in the case of direct-current electrolysis. The action of the positive half wave is not reversed by the action of the negative half wave, and in practice it may be expected that the effect will vary between practically nothing and somewhat less than 1 per cent. of the electrolytic effect of an equal direct current. The Paper concludes with a description of an investigation into the possibility of electrical protection against alternating-current electrolysis. In one of these tests a small direct current was superimposed on the alternating current, and, in many of the trials, a negative electrical corrosion was obtained, that is to say, the total corrosion was less than would occur with no current flowing at all. The conclusion arrived at is that a direct current superimposed on an alternating current, and equal to 1·5 per cent. of the alternating current, perfectly protects lead against electrolytic attack by a 25-cycle current.

H. R. S.

Speaking Condenser. T. ARGYROPOULOS.

(Comptes Rendus de l'Académie des Sciences, Paris, 1907, vol. cxliv. pp. 971–2.)

"Singing condensers" are already known, but the Author has succeeded in making a condenser *speak* clearly and distinctly. A strong microphone is connected in circuit with four accumulators and with one winding of a special transformer, having a laminated iron core 3 or 4 centimetres thick and wound with two insulated copper wires, 2·5 millimetres in diameter, and about 70 metres (76 yards) in length. The other winding of the transformer is connected in circuit with the condenser and with a source of pressure giving a constant potential difference of 220 volts. The

novelty of the Author's experiment consists in the introduction of this pressure-difference, keeping the plates of the condenser charged to a steady potential. The condenser was formed of layers of tinfoil and paraffined-paper, and had a capacity of 7 microfarads. Microphone, transformer, and condenser were each placed in a separate room to avoid any mistake as to the source from which the speaking came, and every word spoken before the microphone was clearly repeated by the condenser. The intensity of the speech increased with the potential difference between the condenser-plates.

W. C. H.

Wireless-Telegraph Receivers. S. M. Kintner.

(Proceedings of the American Institute of Electrical Engineers, New York, January 1907, pp. 65–71.)

Improvements in wireless-telegraph receivers have been much more numerous than those in the sending-apparatus. The ordinary coherer was soon recognized as a delicate and treacherous device, and in 1899 Professor Fessenden and the Author experimented with a receiving arrangement consisting of a galvanometer formed by a small ring suspended at an angle of 45° to the plane of two field-coils. Unfortunately in this form the current in the ring was nearly in 90° phase-relation to the magnetic field, hence the torque was small. The Author then attempted to use a rotary field, which was partially successful. The rotary field was obtained by means of two vertical antennae spaced one quarter wave-length apart, and it was thus possible to tell the direction from which the waves were coming. Professor Fessenden then brought out a device consisting of a very small loop of platinum wire so arranged that the change in its resistance, due to the temperature produced by the oscillating current, was indicated in a telephone, and he called this arrangement a hot-wire "barretter." It was, however, too delicate, as will be evident from the fact that the platinum wire was only 0·00008 inch in diameter and 0·015 inch in length. The next step was to replace the very fine platinum wire by an exceedingly fine liquid resistance, and although the dimensions of this resistance are almost microscopic, the arrangement has proved to be in practice very reliable, and it can even be used on a rolling ship. The resistance is formed by means of a small platinum wire dipping a very short distance into a liquid. Nitric acid has been proved to be the best liquid, but other solutions, such as HCl, KOH, H_2SO_4 have been found satisfactory. The operating-cell works best at 1·6 volt, and the current changes are of the order 10^{-6} ampere, which is an ample current for a telephone, but too small to work a relay with certainty.

H. R. S.

Reinforced-Concrete Towers for High Potential Transmission-Line.

F. W. SCHEIDENHELM.

(Engineering News, New York, 2 May, 1907, pp. 476–8.)

A most unusual structure is described, solving the problem of economically supporting at one end sixteen cables carried 1,014 feet across the Monongahela River at a minimum height over low water of 79 feet 6 inches, the anchorage at the other end being dealt with by the special strengthening of the local sub-station there. The support referred to in the article consists of two reinforced-concrete poles, the higher one 108 feet above base, providing only for the wind-stress on the tower itself, and the weight, including ice-accumulation, of the wires, the remaining stresses being conveyed by means of a roller saddle on the top, to a 38-foot 6-inch anchorage-tower 230 feet behind it. The designs of these two structures are given in detail, with illustrations, but, generally, that of the larger tower may be defined as a hollow square with a 12-inch wall in horizontal section up to 84 feet from the base, where it becomes solid, reinforced at the corners with old 60-lb. T-rails, and spirally with ⅜-inch cable discarded from ferry service, wired to the rails. The tower rises from a reinforced-concrete base 30 feet square, and is 8 feet 2 inches at foot and 1 foot square at top external dimensions. The other tower is solid, 10 feet by 4 feet on a base of 31 feet by 10 feet, and batters up to a section 1 foot square at 41 feet 1 inch height, the tension side being vertical and the section above uniform. The reinforcement is somewhat different from that of the supporting tower, the stresses being definitely in one direction, a condition, owing to wind-pressures, etc., not applicable to the latter. The nature of the cable-connection saddle, etc., is set forth. The concrete was 1 : 2½ : 5 for the footings, and 1 : 2½ : 4 for the walls. The machinery for erection, worked by electricity, and the arrangements for erection, including scaffolding, moulds, etc., are explained. An editorial footnote draws attention to an article in the *Engineering News* of the 4th January, 1906, on "The Structural Design of Towers for Electrical Power-transmission Lines," discussing the theoretical side of the design of such towers.

C. O. B.

Klar River Electrically-worked Movable Dam at Dejefors.

C. J. MAGNELL.

(Teknisk Tidskrift, Stockholm, 1907, Road and Water section, pp. 33–4.)

The river Klar at Dejefors in Sweden has a fall of 8·4 metres (27½ feet) at low water and 7·9 metres (26 feet) at high water. The flow is respectively about 60 and 1,000 cubic metres per second

(13,200 and 220,000 gallons). At 36 kilometres (22⅓ miles) above the fall are the two Munkfors Works, between which the river generally flows steadily, with a stronger current in only a few places. Immediately below Munkfors is a rapid current, having a fall of 0·2 metre in a length of 300 metres (1 in 1,500). As the fall at Dejefors can be dammed to give 11·6 metres (38 feet) at low water, without detriment to the Munkfors fall, the dam has been designed for the increased height of fall. For dealing with the rapid variations in the river the dam must be easy to work, so that sufficient waterway can be provided in a short time. Moreover timber-floating takes place on a large scale, for which the dam must afford wide free openings. These conditions have led to the employment of horizontal rotary dams, which cross the river diagonally, and meet on a central pier, lying nearly at right angles to each other, with their apex pointing down stream. There are four openings for flow; the two nearest the central pier are each 32 metres (105 feet) wide, closed with rollers of 3·5 metres (11½ feet) diameter; and the two outside waterways, each 11 metres (36 feet) wide, are closed by wood needles. Of the two rollers the western weighs 90, and the eastern 108 tons. They are worked by gearing driven electrically, situated on the central pier; each is raised and lowered on rack rails by means of a pitch-chain, which holds the roller in any position under the control of a water-brake. To provide against leakage, wood ribs are let into the bottom and ends of the roller, which bear on the bottom cill and against the side walls of the dam-opening. These can easily be repaired, when the roller is raised. Each roller is divided by a longitudinal partition into two compartments: one to contain water for sinking it after it has been raised, and the other for air to give the requisite flotation. For timber-floating, one of the rollers has a channel across the top, 8 metres broad and 1 metre deep (26¼ by 3¼ feet), which is closed by a spring flap, and when fully open passes 5 cubic metres (1,100 gallons) per second. When the flow exceeds 20 cubic metres (4,400 gallons), the attendant begins to raise the roller itself; and when it is so high that the timber cannot float over, it has to pass under. The electric motor driving the gearing is of 12 HP., capable of raising a roller to the full height in 20 minutes. One roller is generally sufficient for regulating the flow; the second has to be raised only in the spring- and autumn-floods, and the needles only as a last resort. When fully open, the whole dam can pass about 1,300 cubic metres (286,000 gallons) per second. Salmon-ladders enable fish to pass.

The cost of the work is estimated at 180,000 kronor (£10,000), or less than that of any other dam to meet similar requirements; and this dam will be the largest of its kind hitherto constructed. The design is illustrated by three plates of diagrams and sketches.

A. B.

Electric Power-Transmission in Värmland, Sweden.

TORSTEN HOLMGREN.

(Teknisk Tidskrift, Stockholm, 1907, Electrical section, pp. 51–62.)

Ten years ago plans were prepared for transmitting electric power to the town of Karlstad from Deje waterfall in the River Klar, which flows south through the lakes of the province of Värmland, and discharges itself into the northern end of Lake Väner at Karlstad. Other falls—at Forshaga on the same river, and at Edsvalla and Frykfors on the River Nors—though nearer to Karlstad, had already been utilized for the manufacture of wood pulp. Deje fall was only partially employed for the same purpose, and was adequate for future larger requirements. It is due north of Karlstad, at a distance of 27 kilometres (17 miles) as the crow flies. On the Author's proposal it was decided to connect the intended Dejefors power-station with another at Frykfors, situated where the outflow from lower Fryken lake falls into the River Nors. The flow of the Klar at Dejefors varies greatly. For a fortnight or a month in each year it is as low as 50 to 60 cubic metres (11,000 to 13,200 gallons) per second; in floods it goes up to 1,000 cubic metres (220,000 gallons). Frykfors is just below the capacious Fryken lakes, so that, by drawing off from these the quantity required for the power-station during the short time of low water in the Klar, a great economical advantage results from the combination of the Klar and Nors supplies. At Dejefors station the turbines are therefore kept running as long as the water lasts. The Fryken lakes serve as a common storage for both stations. Works at Edsvalla on the River Nors, below Frykfors, have since changed hands, and the new owners now control the whole extent of fall from the Fryken lakes to Lake Väner. The combination of the two watersheds of the Klar and Nors rivers seems thus in a fair way to be completely realised. The Värmland power-distribution has already become the largest in the country, and is the first in Sweden working with so high a tension as 33,000 volts. It has now been running regularly for more than a year.

With the exceptional minimum flow of 50 cubic metres (11,000 gallons) per second, the height of fall at Dejefors is about 9 metres (29½ feet), which will be increased to 11 metres (36 feet) by raising the dam. The electric power-station is at present utilizing 2,000 HP., which as early as possible will be trebled. At Frykfors the power-station is almost ready for 2,250 HP. and 5·1 metres (16¾ feet) fall. Here too the height will be increased to 7·5 metres (24½ feet), and the machinery to 4,000 HP. At Edsvalla the power-station has been begun. In flood the height of fall is 8·5 to 9 metres (28 to 29½ feet), depending on the water-level in Lake Väner, in which variations occur not only yearly, but to a much greater extent over periods of about 10 years. The constant flow in the River Nors is

at least 25 cubic metres (5,500 gallons) per second, which by raising the dams in the Fryken lakes can be increased to 34 cubic metres (7,480 gallons). Three-wire conductors of 30,000 volts are led between Dejefors and Klarafors, and thence to Karlstad, and between Frykfors and Edsvalla and further south to Slottsbron; and a new line runs between Edsvalla and Karlstad, completing a ring circuit with a full reserve for the places of greatest consumption. Karlstad is at present consuming about 400 HP.

Dejefors power-station is remarkable for the absence of visible head-race and tail-race; both are led through tunnels blasted in the rock. There are four turbines of 500 HP. at least height of fall, 7·3 metres (24 feet) in flood, and one magnetizing turbine of 65 HP.; at lowest water (greatest height of fall) they develop 650 HP. The electrical equipment is therefore arranged for a continuous minimum of 2,000 HP. There are four three-phase generators of 50 periods for 410 kilowatts, and one for 210 kilowatts, all for 2,000 volts; also a direct-current generator of 65 HP. at 220 volts, and another at the same tension for lighting. Four single-phase intensifying transformers, each of 550 kilowatt-volt-amperes, raise the voltage from 2,000 to 34,000. The transformers are air-cooled, each provided with its own fan-motor. The entering air is filtered through a screen of close mesh, to exclude dust.

The power-mains to Karlstad are three, formed of hard-drawn copper wire of 10 square millimetres (0·0155 square inch) section, arranged in an equilateral triangle of 1 metre (40-inch) sides. They are carried on slender fir-poles impregnated with creosote oil, which are placed 45 metres (150 feet) apart. The insulators are of bell-petticoat form, packed on their brackets with black oakum, and tested against rain with 70,000 volts between the wire and the bracket; the latter is fixed to the pole with wood screws. At Skifed, immediately below Forshaga, the River Klar is crossed by phosphor-bronze wires carried on a lattice viaduct well earthed with a span of 112 metres (368 feet). At Klarafors junction of the three mains is a transformer-station of two storeys; the upper contains the high-tension instruments and lightning-conductor. Oil cut-outs are used.

Corresponding particulars are given of the stations at Frykfors and Karlstad, and of the works supplied with electricity in Klarafors. A list is added of all the interruptions and delays which occurred in June 1906 to March 1907; they were more noticeable in wet weather than in fine.

An excellent map shows the entire district; and the works are illustrated by a number of photographs and drawings.

A. B.

Electric Power-Transmission and Lighting for Grängesberg Mining District.

(Teknisk Tidskrift, Stockholm, 1907, Electrotechnic section, pp. 3–6.)

From the earliest days of power-transmission by electricity, the Grängesberg mining-district in Sweden has taken the lead in its application. In 1892 the first three-phase transmission proper was started in Sweden, between Hellsjön and Grängesberg, of 400 HP. and 10,000 volts. It is still working without alteration. It was applied at once to a number of purposes, by means of a high-tension circuit having extensive ramifications. Increasing demands for power called for additional stations and mains, so that there is now 4,000 HP. supplied by three power-stations at Hellsjön, Enkullen and Lembo. Recently a central distributing-station has been built, to meet the highest requirements of trustworthiness in working, and to carry out the adaptation of modern principles. The building is entirely of stone and iron. It is in two sections at right-angles, forming an L shape in plan: one section contains the power-supply, three-phase 8,500 volts; the other is for lighting, single-phase 5,000 volts. Both departments admit of extension by shifting the gable-walls outwards. There are three storeys, the topmost twice the height of either of the two below; it contains the omnibus-bars and all the high-tension apparatus. In the intermediate storey are the switch-boards, with low-tension only, and a superintendent's room with central telephone to the power-stations and to different points in the circuit. On the ground floor are two transformer-substations for supplying the immediate neighbourhood, one for power and one for light, and a stand-by of reserve apparatus. In the open roof of the top storey are arranged lightning-conductor, switches, meters for the transformers, and other appliances, rendered accessible by a gallery running all round. An external balcony affords access to the outside mains. The latter are brought in under the cornice through slanting tubes of hard coarse porcelain. The lightning-conductor has double groups of points; one group is coupled in series with water-resistances. Inside the house all mains are insulated with thick gutta-percha. Where bright parts occur, as at switches, partitions are erected of uralite, a refractory material which has proved particularly suitable. The mains from the transformers are carried through the walls to knife-edge switches by means of bolts connecting strong porcelain insulators, one on each side of the wall. They are designated "comb-flange" insulators, and are of conical shape, each being turned with a succession of grooves, so that the contour of the intermediate flanges resembles the teeth of a comb. The same insulators carry also the omnibus bars, which are enclosed in troughs with uralite walls. The oil-switches are worked by levers on the switch-board in the intermediate storey, in combination with fuses, which break the circuit at overload, at the same time lighting a lamp on the lever, and ringing a bell.

The lighting distribution is arranged on much the same plan as that for power, but is simpler, owing to the lower tension and the less stringent requirements for security against breakdown. The circuit is fed either from a special single-phase line, or else, where the lights are divided into two groups, from the power system, whereby three-phase and two-phase transformers are brought into use. The transformers on the ground floor deliver their currents of medium or low tension through underground cables; their oil-cups are worked by hand from the first-floor room. The electrical equipment has been carried out on such a scale of strength that the tension could be doubled without causing inconvenience.

A. B.

Engineering Chemistry in the Power-Plant.

(Engineering Record, New York, 13 April, 1907, pp. 453–4.)

This is a powerful claim for the more extended employment of what may be called the chemical engineer, in the design and working of both steam- and gas-power plants, on the ground especially of saving in fuel-consumption. It is urged that the analysis of combustion-conditions is a task for the specialist, who must be able not only to report on the fulfilment of fuel-contracts on the basis of heat-units, but also to advise as to the best kind of coal for a given battery of boilers and the proper methods of controlling the actual performance of the grates. Enlarging on this, the Author shows that the chemical work should include analysis with respect to calorific power, fixed carbon, ash, moisture, the use of the pyrometer in the furnaces and boiler-passes, the investigation of the smoke-problem, the air-supply under forced-draught, rates of combustion for different styles of grates and stokers, analysis of feed-water, etc. As to gas-plants, it is pointed out that specialized attention is even more wanted in respect to the reactions of the gas-making process, the control of the enriching steam-supply, the ultilization of residues, removal of tar, air-supply, and quality of the gas. Hitherto, attention has been fixed mainly on the design and the improvement of apparatus, but in the future, in addition to these, the economy of working in which engineering chemistry has its part must share the attention of the owners of any successful power-plant. C. O. B.

Power-Transmission by Shafting. Ottorino Pomini.

(Il Politecnico, Milan, April, 1907, pp. 189–202.)

The Author points out the disagreement between the various existing Tables and formulas showing the safe diameter of shafting for a given output and also the general want of agreement between theory and practice.

This want of agreement is considered to be due to the fact that the conditions assumed for the deviation of the various formulas are not altogether such as obtain in general practice, and is specially due to the fact that lines of shafting have to withstand both a bending- and a twisting-moment. The relative importance of these two stresses varies according to the size of shaft and power transmitted, the bending-moments being of primary importance in small shafts and of much less importance in the case of large shafts transmitting a considerable power. The formulas in use at present are only applicable over limited ranges, and it is necessary to employ various modifications for any particular case. In order to prepare a Table which shall embody the requirements of modern practice and at the same time be applicable over a wide range the Author considers three typical cases of power-transmission by shafting. Calculating the bending-moments in each of these cases and allowing a maximum permissible intensity of 3·25 tons per square inch for the combined bending- and twisting-stress, the maximum torsional strain is obtained, and from these values the Author prepares a Table giving the diameters of shafts necessary for transmitting 3 to 1,000 HP. at speeds of 60 to 400 revolutions per minute. The article is illustrated by several curves and diagrams.

L. F. M.

Steam Power-Station, Twin City Rapid Transit Company, Minneapolis.

(Proceedings of the American Institute of Electrical Engineers, New York, February, 1907, pp. 3–12.)

This is an editorial note giving the leading particulars of a steam power-station having a capacity of 27,000 kilowatts, and operating in parallel with a water power-station of 10,000 HP. capacity. The steam power-station works during the day only and takes the peaks; the water power-station works continuously. The steam power-station contains twenty-four boilers, each of a nominal capacity of 556 HP., and an overload capacity of 825 HP. The working-pressure is 200 lbs. per square inch, and each boiler has a superheater capable of producing 120° Fahr. superheat. There are four vertical cross-compound condensing-engines driving three-phase, revolving-field, flywheel-type generators; the nominal capacity of each set is 5,000 I.HP., and the overload capacity is 9,000. There are also two turbine sets of the Curtis type of 5,000 kilowatts, with 100 per cent. overload capacity. The note gives the leading particulars, dimensions, and guarantees of all the items included in the power-station, such as buildings, chimneys, pumps of all kinds, bunkers, coal-conveyors, pipe-work, switchboards, etc. The following are some of the particulars given: The chimneys are guaranteed to withstand a wind-pressure of 50 lbs. per square foot. The coal-crusher and conveyor has a capacity of 75 tons per hour, is driven by a 7·5-HP. electric motor, and travels 100 feet per minute; the

feed-water heaters (two) are each guaranteed to heat 350,000 lbs. of water 60° to 210° F., with steam at atmospheric pressure. The steam-consumption of the main engines is 11½ lbs. per HP.-hour, with steam at 175 lbs. gauge-pressure, 75° F. superheat, and 26-inch vacuum; for the turbines the steam-consumption is, with 175 gauge-pressure, 2-inch absolute back-pressure and 100° F. superheat, for half load, 18·3 lbs.; full load, 17 lbs.; 1½ load, 17·5 lbs. per kilowatt-hour. The insulation test was 26,200 volts alternating for one minute.

H. R. S.

Ville-de-Paris Dirigible Balloon. LUCIEN FOURNIER.

(La Nature, Paris, 18 May, 1907, pp. 388-90.)

During 1906 three different types of air-ships were produced at Paris—the De-la-Vaulx, the Patrie and the Ville-de-Paris. This last was one of a series constructed by Mr. Tatin for Mr. Henri Deutsch de la Meurthe. The present balloon is in full accordance with the theories propounded by Colonel Renard, and is being prepared in a special shed constructed for the purpose at Sartrouville. This building is 228 feet long, 36 feet wide, and 59 feet in height. It is floored over, but it contains a hemispherical pit, 23 feet in diameter, for screw-propeller tests. The general form of the balloon is that of a cigar or spindle, with a diameter at the widest part of 34·44 feet, and an extreme length of 165·37 feet. It has a cubic capacity of 112,800 cubic feet. Its weight complete is 1,826 lbs., and it is thus the most powerful machine yet produced. A feature which is entirely novel is the feathering-gear in the rear, which consists of eight smaller cylindrical balloons, four of them 31·3 feet in length with a diameter of 5·25 feet, and the others of the same length but only 3·18 feet in diameter. These smaller balloons are fixed lengthwise against the rear of the balloon in the form of a cross, as the feathers might be on an arrow. They are conical-ended in front and semispherical in the rear, and are shrouded so as to maintain their shape. The balloon, which contains an internal air-balloon, is divided into three compartments by two transverse partitions. The air-balloon is fed by a fan driven at 1,530 revolutions per minute and supplying 255,000 cubic feet per hour at a pressure of 1·18 inch of water. The car is a truss formed of white-pine, the tension-rods and strainers consisting of steel wire. It is fusiform in shape and has a total length of 114·82 feet. The car is suspended from the balloon by means of fifty steel wire ropes at a distance of 18 feet below it. The Chenu motor is of 70 HP., making 900 revolutions per minute. The screw of 20 feet diameter is in front. The back part of the car reserved for the passengers is occupied during the trial trips by 881 lbs. of ballast. The two rudders in the rear have an area of 150 square feet.

G. R. R.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1906–1907.—Part IV.

N.B.—Titles in italics refer to Original Papers, and those selected for printing only are further distinguished by the suffix "(S.)." Abstracted Papers are not so indicated.

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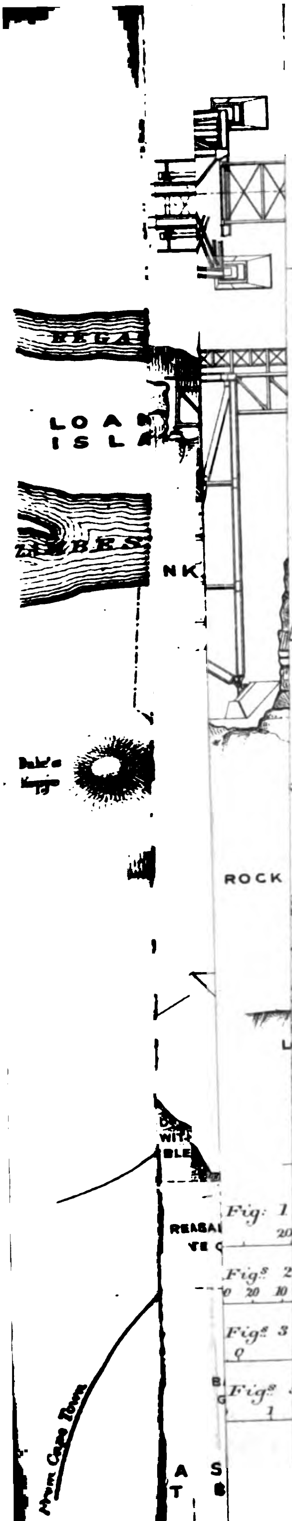
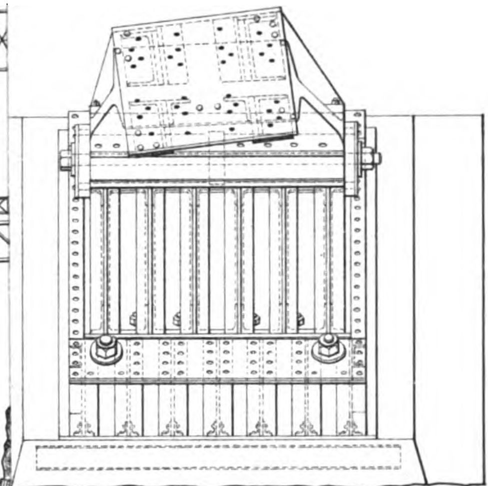
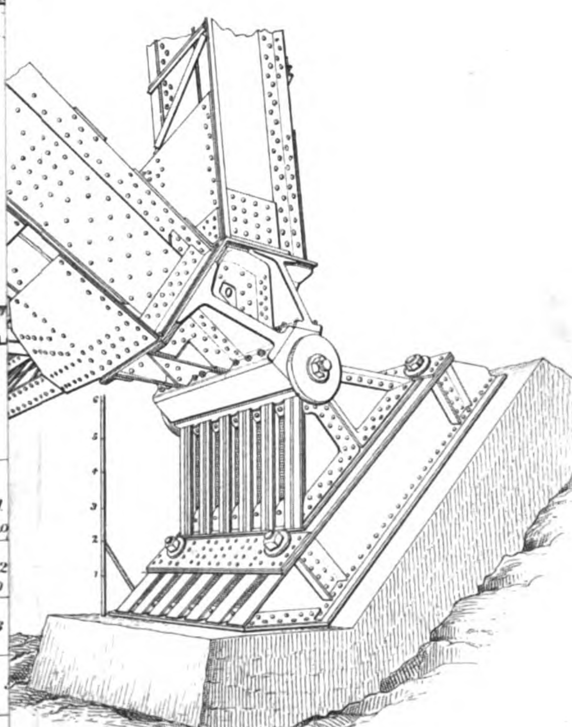




FRONT ELEVATION.



PERSPECTIVE VIEW.

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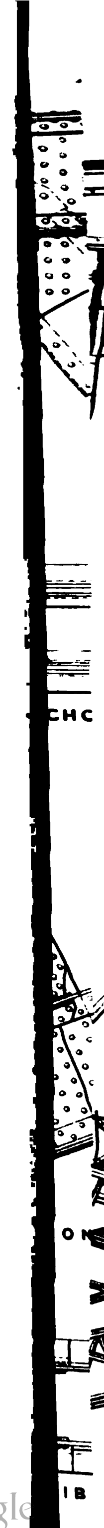

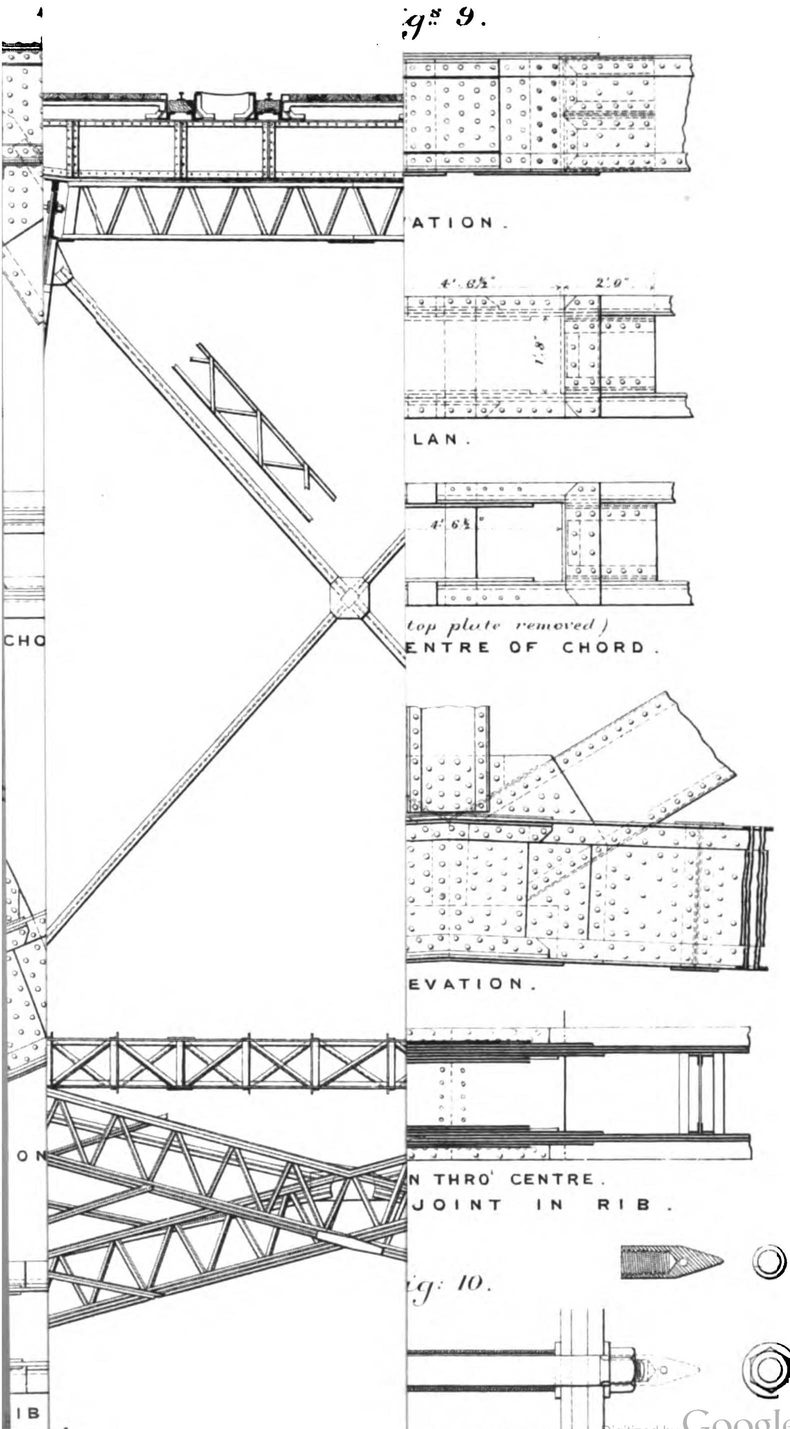

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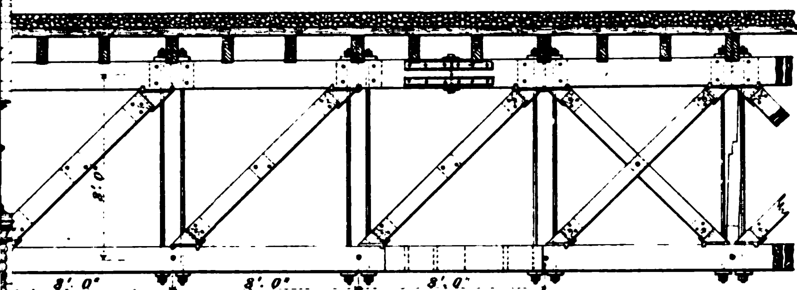
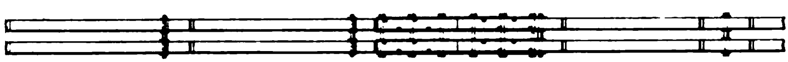
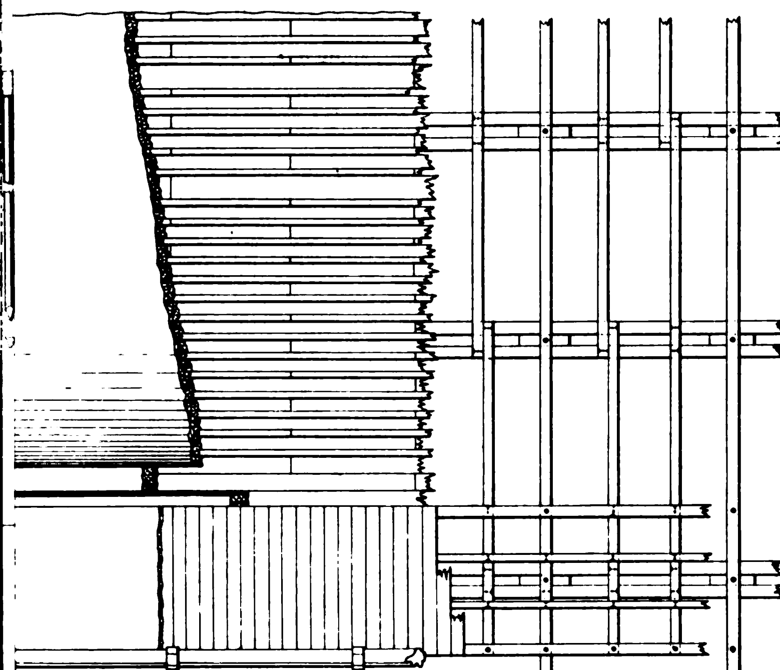
INVERTED PLAN OF TOP CHORD.



SECTION AT CENTRE.



PLAN AT LOWER CHORD.



TAILS OF TIMBER SIDE SPANS.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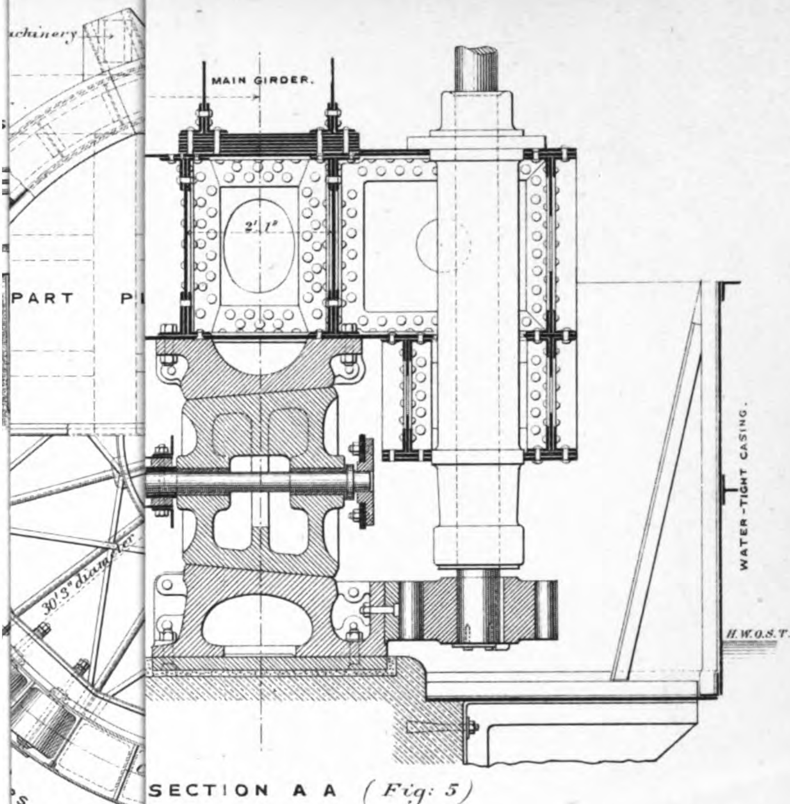

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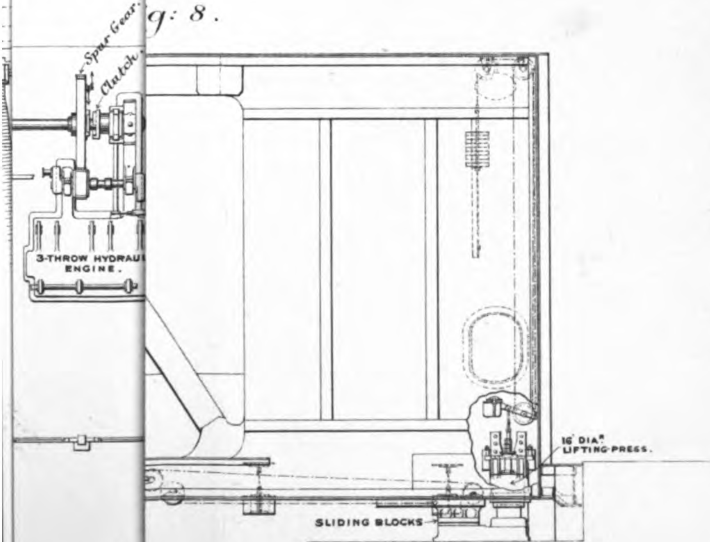
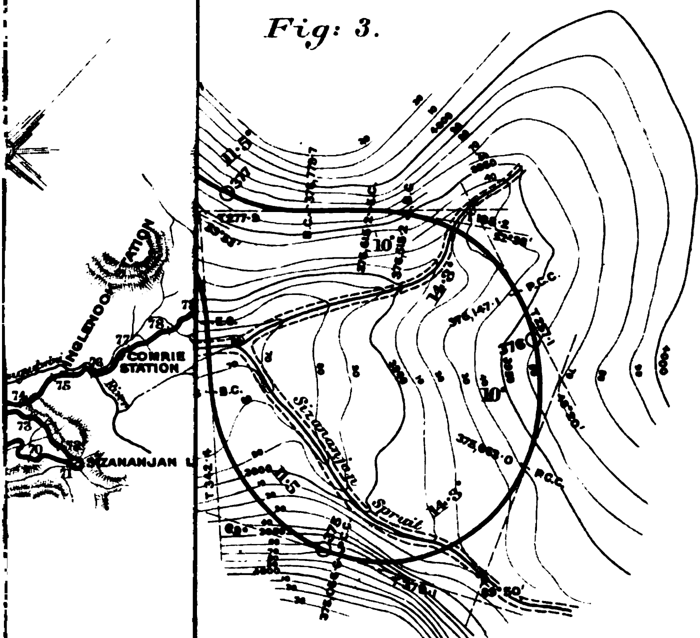


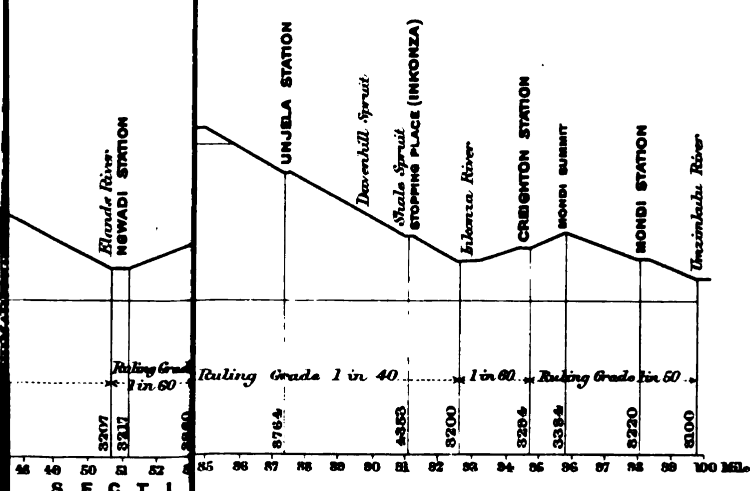
ERAL ARR OF END OF SWING SPAN.

Fig: 3.



UPPER SIZANANJAN LOOP

Fig: 2.



S E C T I

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THOS KELL & SON, LITH 40 KING ST COVENT GARDEN.